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SHOCK (RANKINE -- HUGONIOT) RELATIONS FOR VARIOUS ALTITUDES

FROM SEA LEVEL TO 300,000 FEET

14 APRIL 1958

U.S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

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NAVORD REPORT 6075

NORMAL SHOCK (RANKINE-HUGONIOT) RELATIONS FOR VARIOUS ALTITUDES FROM SEA LEVEL TO 300,000 FEET

By:

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ABSTRACT: The normal shock (Rankine-Hugoniot) relations are presented in tabular form for altitudes ranging from sea level to 300,000 feet in 50,000 feet intervals. The range of shock temperatures extends from 288.16°K to 316,228°K for sea level; for each of the other altitudes, the range extends from 2000°K to 316,228°K, or to the temperature at which radiation pressure and radiation energy become important (whichever is the lower).

The effects of altitude on the normal shock relations are summarized by plots showing that for strong shocks in air, the dimensionless values for shock temperature, density, and gamma as functions of shock strength, are quite sensitive to altitude changes. For weak to moderately strong shocks, however, these relations are relatively insensitive to altitude changes. The dimensionless values of shock velocity and energy density are comparatively insensitive to altitude even for strong shocks.

U. S. NAVAL ORDNANCE LABORATORY
White Oak, Silver Spring, Maryland

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The calculations presented in this report were made in conjunction with a series of studies of the effect of altitude on explosion phenomena being conducted at NOL by the Air-Ground Explosions Division. They were made as a part of Task No. 701-267/76002/01040 under the auspices of the Bureau of Ordnance and comprise a partial solution of Key Problem #12, ("Key Problems in Explosives Research and Development", NAVORD 4299) of the Air Defense Systems section.

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1. INTRODUCTION

The purpose of the present work was to investigate the effect of altitude on the normal shock (Rankine-Hugoniot) relations and to present these relations in convenient tabular form for various altitudes from sea level to 300,000 feet. The calculations were based on currently accepted equation of state data* computed by J. Hilsenrath and co-workers of the National Bureau of Standards (references 1, 2, and 3) and the ARDC model atmosphere (reference 4) accepted by the National Advisory Committee for Aeronautics up to 160,000 feet and, tentatively, up to 300,000 feet.

The properties of a shock wave in air depend upon the conditions in front of the shock, and hence, upon the altitude. As demonstrated in section 2, however, the various relations between the shock parameters expressed in dimensionless form** are independent of the conditions in front of the shock if the fluid behaves as a perfect gas with constant specific heats; these relations are relatively insensitive to variation in altitude for weak or moderately strong shocks and some remain relatively insensitive to variation in altitude for strong shocks while others become quite sensitive.

The shock front parameters are completely determined by specification of the conditions in front of the shock and one additional parameter, e.g., the shock temperature. Thus, if the atmospheric conditions are known for each altitude, then the density, pressure, particle velocity, and specific

* Equation of state calculations made prior to those of references 1, 2, and 3 are inaccurate at sufficiently high temperatures for dissociation effects to manifest themselves due to an inaccurate value of the dissociation energy of nitrogen.

** The proper dimensionless form is obtained by dividing each variable of state behind the shock by the value of that variable of state in front of the shock and by dividing each velocity by the speed of sound in front of the shock.

internal energy behind the front, and the shock velocity can be computed as functions of the shock temperature. The procedure utilized in the present calculations is described in section 3. The atmospheric conditions for each altitude (obtained from reference 4) are presented in table I.

The effect of radiation pressure, radiation energy density, and radiative broadening of the shock front are mentioned briefly and the approximate temperature at which the first two of these become important at each altitude is indicated.

The normal shock relations are presented in tabular form in tables II through VIII, for the altitude range mentioned above, in 50,000 feet intervals. The sea-level values are for a range of shock temperatures from 288.16°K to 316,228°K; the values for all other altitudes are for a range from 2000°K to 316,228°K or to the temperature at which radiation effects become important (whichever is the lower). The illustrations show the variables in dimensionless form as functions of the pressure behind the shock divided by the pressure in front of the shock. It can be seen that significant differences exist between some of the shock relations for altitudes differing by, e.g., 50,000 feet; others are nearly invariant to such moderate altitude variations.

The results of the calculations are discussed in section 5.

2. THE EFFECT OF ALTITUDE ON THE NORMAL SHOCK RELATIONS

The conventional model for a shock front consists of a surface across which the flow variables (e.g., pressure, density, particle velocity) are assumed to undergo discontinuous changes consistent with the laws of conservation of mass, momentum, and energy. These laws provide the following three equations:

(1) $\rho_0(u_0 - U) = \rho_s(u_s - U)$ (conservation of mass)

(2) $\rho_s u_s(u_s - U) - \rho_0 u_0(u_0 - U) = P_0 - P_s$ (conservation of momentum)

$$(3) \quad \rho_s\left(\tfrac{1}{2}u_s^2 + E_s\right)(u_s - U) - \rho_o\left(\tfrac{1}{2}u_o^2 + E_o\right)(u_o - U)$$

$$= P_o u_o - P_s u_s \qquad \text{(conservation of energy).}$$

Here the symbols ρ, u, P, U, and E denote density, particle velocity, pressure, shock velocity, and internal energy per unit mass, respectively; the subscript s refers to the shocked side and the subscript o to the unshocked side of the shock front. If the air in front of the shock behaves as a perfect gas with constant specific heat ratio γ_o, then

$$(4) \qquad E_o = \frac{P_o}{(\gamma_o - 1)\rho_o}$$

and

$$(5) \qquad c_o = \sqrt{\frac{\gamma_o P_o}{\rho_o}}$$

where c_o is the speed of sound. It is expedient to define an effective ratio of specific heats, γ_s, for the shocked side of the shock front by the relation

$$(6) \qquad E_s = \frac{P_s}{(\gamma_s - 1)\rho_s} \quad .$$

The variable, γ_s, so defined serves as an index which indicates the extent to which the equation of state relating pressure, density, and specific internal energy deviates from perfect gas behavior.

By use of relations (4), (5), and (6), the three conservation laws can be expressed as

$$(7) \qquad \left(\frac{u_o}{c_o} - \frac{U}{c_o}\right) = \frac{\rho_s}{\rho_o}\left(\frac{u_s}{c_o} - \frac{U}{c_o}\right),$$

$$(8)\qquad \frac{\rho_s}{\rho_o}\left(\frac{u_s}{c_o}\right)\left(\frac{u_s}{c_o}-\frac{U}{c_o}\right) - \frac{u_o}{c_o}\left(\frac{u_o}{c_o}-\frac{U}{c_o}\right) = \frac{1}{\gamma_o}\left(1-\frac{P_s}{P_o}\right),$$

and

$$(9)\qquad \frac{\rho_s}{\rho_o}\left[\frac{1}{2}\left(\frac{u_s}{c_o}\right)^2 + \frac{1}{(\gamma_s-1)\gamma_o}\left(\frac{E_s}{E_o}\right)\right]\left(\frac{u_s}{c_o}-\frac{U}{c_o}\right)$$

$$-\left[\frac{1}{2}\left(\frac{u_o}{c_o}\right)^2 + \frac{1}{(\gamma_o-1)\gamma_o}\right]\left(\frac{u_o}{c_o}-\frac{U}{c_o}\right)$$

$$= \frac{1}{\gamma_o}\left(\frac{u_o}{c_o}\right) - \frac{1}{\gamma_o}\left(\frac{P_s}{P_o}\right)\left(\frac{u_s}{c_o}\right),$$

where

$$(10)\qquad \frac{E_s}{E_o} = \frac{P_s}{P_o}\left(\frac{\rho_o}{\rho_s}\right)\frac{\gamma_o-1}{\gamma_s-1}\ .$$

Note that equations (7) through (10) comprise four independent relations between the eight dimensionless variables P_s/P_o, U/c_o, u_s/c_o, ρ_s/ρ_o, E_s/E_o, u_o/c_o, γ_s, and γ_o. The frame of reference can be chosen to be stationary relative to the unshocked air; thus, u_o can be set equal to zero and thereby eliminated from the equations. For a perfect gas, the effective ratios of specific heats, γ_s and γ_o are equal to the true ratio of specific heats and are independent of the thermodynamic state (i.e., $\gamma_s = \gamma_o = C_p/C_v$ = constant, where C_p is the specific heat at constant pressure and C_v the specific heat at constant volume for a perfect gas). Thus, for a perfect gas the specific heat ratio is a constant parameter and equations (7) through (10) comprise four independent relations between five dimensionless

variables which are independent of the ambient conditions. For shocks of weak to moderate strength, air behaves approximately as a perfect gas, and consequently, the normal shock relations expressed in dimensionless form are approximately independent of ambient conditions (and, hence, altitude).

In order to ascertain, in general, the effect of altitude on the normal shock relations (in dimensionless form) it is convenient to attribute this effect to variation in γ_s (and to variation in the compressibility factor if the temperature ratio is to be considered). Consider the following set of relations obtained from equations (7) through (10) by setting u_0 equal to zero and solving for U/c_0, u_s/c_0, ρ_s/ρ_0, and E_s/E_0 as functions of P_s/P_0:

$$(11) \qquad \frac{\rho_s}{\rho_0} = \frac{1 + \frac{\gamma_s+1}{\gamma_s-1}\left(\frac{P_s}{P_0}\right)}{\frac{\gamma_0+1}{\gamma_0-1} + \frac{P_s}{P_0}}$$

$$(12) \qquad \frac{U}{c_0} = \left\{\frac{\left[\frac{P_s}{P_0} - 1\right]\left[\frac{\gamma_s+1}{\gamma_s-1}\left(\frac{P_s}{P_0}\right) + 1\right]}{\gamma_0\left[\frac{P_s}{P_0}\left(\frac{\gamma_s+1}{\gamma_s-1} - 1\right) + 1 - \frac{\gamma_0+1}{\gamma_0-1}\right]}\right\}^{\frac{1}{2}}$$

$$(13) \qquad \frac{u_s}{c_0} = \frac{U}{c_0}\left[\frac{1 - \frac{\gamma_s+1}{\gamma_s-1} + \frac{P_s}{P_0}\left(\frac{\gamma_s+1}{\gamma_s-1} - 1\right)}{1 + \frac{\gamma_s+1}{\gamma_s-1}\,\frac{P_s}{P_0}}\right]$$

$$(14) \qquad \frac{E_s}{E_0} = \left(\frac{P_s}{P_0}\right)\left(\frac{\rho_0}{\rho_s}\right)\left(\frac{\gamma_0-1}{\gamma_s-1}\right)$$

$$= \left(\frac{\gamma_0-1}{\gamma_s-1}\right)\left(\frac{P_s}{P_0}\right)\left[\frac{\frac{\gamma_0+1}{\gamma_0-1} + \frac{P_s}{P_0}}{1 + \frac{\gamma_s+1}{\gamma_s-1}\left(\frac{P_s}{P_0}\right)}\right].$$

The corresponding relation for the temperature ratio can be obtained by introducing the compressibility factor, Z. The thermal equation of state can be written formally as

$$(15) \qquad \frac{P}{\rho R T} = Z$$

where R is a constant reference value of the gas constant per unit mass taken such that Z is equal to unity for the unshocked state. Thus, the temperature ratio is given by

$$(16) \qquad \frac{T_s}{T_0} = \left(\frac{P_s}{P_0}\right)\left(\frac{\rho_0}{\rho_s}\right)\left(\frac{1}{Z_s}\right) = \frac{1}{Z_s}\left(\frac{P_s}{P_0}\right)\left[\frac{\frac{\gamma_s+1}{\gamma_s-1} + \frac{P_s}{P_0}}{1 + \frac{\gamma_s+1}{\gamma_s-1}\left(\frac{P_s}{P_0}\right)}\right].$$

If the functional relationship between γ_s and P_s/P_0 (see figure III) and that between Z_s and P_s/P_0 were not dependent upon ambient conditions, the relations between the dimensionless variables would not vary with altitude as can be inferred by inspection of equations (11) through (14) and equation (16). This is true for a perfect gas and is approximately true for shocks of weak to moderate strength in air. For strong shocks in air, this is not true, and as a consequence, while some of the relations are relatively insensitive to altitude, others are quite sensitive. This can be demonstrated by considering each of the relations (11), (12), (13), (14), and (16), and assuming typical values for γ_s and Z_s.

Since the altitude effect is greatest if the shock is strong, it will be convenient for the present discussion to assume that P_0 is negligible in comparison to P_s in the equations. Equation (11), in the strong shock approximation, reduces to

$$(17) \qquad \frac{\rho_s}{\rho_0} = \frac{\gamma_s + 1}{\gamma_s - 1}$$

From figure III, typical values of γ_s are taken to be 1.4, 1.3, 1.2, and 1.1 for the temperature and altitude ranges considered here. Introducing these values into (17) yields for the density ratio, 6, 7-2/3, 11, and 21, respectively. Equation (12), in the strong shock approximation, reduces to

$$(18) \qquad \frac{U}{c_o} = \left[\frac{\gamma_s + 1}{2\gamma_o}\right]^{\frac{1}{2}} \left(\frac{P_s}{P_o}\right)^{\frac{1}{2}} ;$$

taking the same set of values for γ_s yields, for the factor $\left[\frac{\gamma_s + 1}{2\gamma_o}\right]^{\frac{1}{2}}$, .926, .906, .886, and .866, respectively. Note that this relation is much less affected by gas imperfection than (17) and consequently, is expected to be much less sensitive to altitude variation.
Equation (13) reduces to

$$(19) \qquad \frac{u_s}{c_o} = \left[\frac{2}{\gamma_s+1}\left(\frac{\gamma_s + 1}{2\gamma_o}\right)^{\frac{1}{2}}\right]\left(\frac{P_s}{P_o}\right)^{\frac{1}{2}} .$$

For the same set of γ_s values, the coefficient of $(P_s/P_o)^{1/2}$ is .772, .788, .806, and .825; hence, this equation is relatively insensitive to gas imperfection and is expected to be insensitive to altitude variation. Equation (14) reduces to

$$(20) \qquad \frac{E_s}{E_o} = \frac{\gamma_o - 1}{\gamma_s + 1}\left(\frac{P_s}{P_o}\right)$$

For the set of γ_s values, the factor $\frac{\gamma_o - 1}{\gamma_s + 1}$ takes on the values .167, .174, .182, and .190; hence the equation is relatively insensitive.

The effect of gas imperfection and of altitude on the relation between any pair of the dimensionless variables P_s/P_o, U/c_o, u_s/c_o, ρ_s/ρ_o, and E_s/E_o can be interpreted as a variation in the effective specific heat ratio γ_s. The effect on the relation between T_s/T_o and any one of

the other dimensionless variables manifests itself through both γ_s and Z_s. In the strong shock approximation, relation (16) reduces to

$$(21) \qquad \frac{T_s}{T_o} = \frac{1}{Z_s}\left(\frac{\gamma_s - 1}{\gamma_s + 1}\right)\left(\frac{P_s}{P_o}\right)$$

for the above set of γ_s values, and the factor $\frac{\gamma_s - 1}{\gamma_s + 1}$ takes on the values 1/6, 1/7.67, 1/11, and 1/21 which cause a large deviation from the perfect gas relations. In addition to this, for temperatures from 3000°K to 300,000°K, Z_s increases from 1 up to roughly 10 or 12. Thus, relation (21) is expected to be very sensitive to gas imperfection and altitude. Recapitulating, the following characteristics of the (normal shock) relations between any two of the dimensionless variables P_s/P_o, U/c_o, u_s/c_o, ρ_s/ρ_o, E_s/E_o, and T_s/T_o, were noted:

(i) for perfect gases the relations are invarient to change in ambient conditions;

(ii) for shocks of weak to moderate strength in air (for which $Z_s \simeq Z_o = 1$ and $\gamma_s \simeq \gamma_o = 1.4$) the relations are relatively insensitive to change in ambient conditions (e.g., change in altitude);

(iii) for strong shocks in air, some of the relations are very sensitive to ambient conditions (e.g., ρ_s/ρ_o vs P_s/P_o and T_s/T_o vs P_s/P_o) and others are relatively insensitive to ambient conditions (e.g., U/c_o vs P_s/P_o, E_s/E_o vs P_s/P_o, and u_s/c_o vs P_s/P_o).

3. COMPUTATIONAL PROCEDURE

The normal shock (Rankine-Hugoniot) relations

$$(22) \qquad E_s - E_o = \frac{1}{2}(P_s + P_o)\left(\frac{1}{\rho_o} - \frac{1}{\rho_s}\right)$$

and

$$(23) \qquad U = \sqrt{\frac{\rho_s (P_s - P_o)}{\rho_o (\rho_s - \rho_o)}}$$

can be derived directly from the conservation relations (1), (2), and (3). (Here the notation is the same as that of section 2: E, P, ρ, and U denote internal energy per unit mass, pressure, density, and shock velocity, respectively, and the subscripts s and o refer to the states on the shock and unshocked sides of the shock front, respectively.) The equations of state

$$(24) \qquad P = P(\rho, T)$$

and

$$(25) \qquad E = E(\rho, T)$$

are obtainable from tables of the thermodynamic properties of air (e.g., the tables of references 1, 2, and 3 prepared at the National Bureau of Standards). For each given set of ambient conditions (P_o, ρ_o, T_o, and E_o), relations (22), (23), (24), and (25) can be solved simultaneously for the shock variables U, P_s, E_s, and ρ_s as functions of T_s and expressed in tabular form.

The procedure utilized in the present work is the following*. Let equation (22) be written in the form**

---

* The linear interpolation procedure described here was suitable for the calculations at shock temperatures above 2000°K but was not sufficiently accurate for lower temperatures. The low temperature calculations for the altitude range considered here and the calculation procedure by which they were made will be presented in a subsequent report. The present report is concerned with temperatures above 2000°K; however, the lower temperature sea-level calculations have been included for the convenience of the reader.

** Note that for strong shocks $P_s \gg P_o$ and $E_s \gg E_o$ and, thus, equation (26) could be approximated by

$$E_s = \frac{1}{2} P_s \left(\frac{1}{\rho_o} - \frac{1}{\rho_s} \right)$$

This approximation was not employed in the present calculations.

$$(26) \qquad \frac{2(E_s - E_0)}{P_s + P_0} = \frac{1}{\rho_0}\left(1 - \frac{\rho_0}{\rho_s}\right)$$

and define x and y by the equations

$$(27) \qquad y = y(\rho) = \frac{2\left[E(\rho, T_s) - E_0\right]}{P(\rho, T_s) + P_0}$$

and

$$(28) \qquad x = x(\rho) = \frac{1}{\rho_0}\left(1 - \frac{\rho_0}{\rho}\right) .$$

If y is plotted against x for a given shock temperature, T_s, and unshocked state (P_0, E_0), there is a point at which the ordinate equals the abscissa; at this point ρ equals ρ_s. From the tables represented formally by (24) and (25), data for the determination of two points (x_1, y_1) and (x_2, y_2) of the curve given parametrically by (27) and (28) can be obtained.

The points 1 and 2 should be such that ρ_1 and ρ_2 are the corresponding density values taken from the tables which are the nearest to the shock values, ρ_s, one being slightly larger and the other slightly smaller. Then the point (x_s, y_s) at which the Rankine-Hugoniot relation (26) is satisfied can be obtained by linear interpolation; i.e., the equation

$$(29) \qquad x_s = y_s = \frac{x_1(y_2 - y_1) - y_1(x_2 - x_1)}{(y_2 - y_1) - (x_2 - x_1)}$$

determines the shock value x_s corresponding to ρ_s.

Thus, the first step in the procedure was to determine the shock density ρ_s from equations (28) and (29). The shock pressure P_s can then be obtained by interpolation in the table represented by (24). Linear interpolation was used in the present work, P_s being computed from the relation

$$(30) \qquad P_s = P_1 + (P_2 - P_1)F$$

where

$$(31) \qquad F = \frac{\frac{\rho_s}{\rho_o} - \frac{\rho_1}{\rho_o}}{\frac{\rho_2}{\rho_o} - \frac{\rho_1}{\rho_o}} .$$

Next the shock velocity, U, was computed from equation (23). The specific internal energy behind the shock front, E_s, can be obtained approximately by interpolation in the table represented by (25). Linear interpolation was used, E_s being obtained from the relation

$$(32) \qquad E_s = E_1 - (E_1 - E_2)F .$$

The effective ratio of specific heats behind the shock front, γ_s, was then computed from

$$(33) \qquad E_s = \frac{P_s}{(\gamma_s - 1)\rho_s} .$$

The particle velocity, u_s, can be computed from the expression

$$(34) \qquad u_s = U\left(1 - \frac{\rho_o}{\rho_s}\right)$$

but was not included in the present work.

The above procedure was carried out on an IBM 650 calculator for a closely spaced series of shock temperatures and for seven different sets of ambient conditions, covering the altitude range from sea level to 300,000 feet in 50,000 feet intervals.

4. EFFECT OF RADIATION

Radiation pressure and radiation energy influence the properties of very intense shock waves and, consequently, modifications in the normal shock relations must be made to take account of these effects. The radiation corrections become significant when the radiation energy density aT^4 becomes comparable to the internal energy density ρE of the material medium (e.g., air) and the radiation pressure $aT^4/3$ becomes comparable to the material pressure P. It has been pointed out by R. G. Sachs (reference 5) that the pressure and energy density terms occurring in the three conservation relations applied across the shock front must be the net values, i.e., the sums of the material and radiation contributions. Thus, the conservation of momentum (equation (2)) must be modified by the addition of the corresponding radiation pressure to each of the material pressure terms and the conservation of energy (equation 3)) by the addition of radiation pressure and radiation energy terms; the conservation of mass is not affected by the presence of radiation.

For shocks propagating in the atmosphere near sea level, shock temperatures of the order of millions of degrees are required before radiation pressure and energy density effects become significant. The calculations contained herein for sea level and 50,000 feet (which are for shock temperatures ranging up to 316,000°K) require no radiation correction. For altitudes of 100,000 feet, 150,000 feet, 200,000 feet, 250,000 feet, and 300,000 feet, the radiation contributions to the pressure and energy density are less than 1% for temperatures up to 251,000°K, 125,000°K, 70,000°K, 31,000°K, and 14,000°K, respectively, and less than 10% for temperatures up to 316,000°K, 251,000°K, 158,000°K, 89,000°K, and 31,000°K, respectively. No radiation corrections were made in the present calculation and the results are not given for temperatures above which the correction needed exceeds 10%.

In reference 5, Sachs also noted that radiative diffusion would affect the thickness of the shock front. A quantitative investigation

of the radiative contribution to the width of the shock front has been carried out by Hari K. Sen and Arnold W. Guess (reference 6). They noted that the radiative contribution depends primarily on the ratio of the mean free path of radiation to that of the material particles, that this radiation effect may be important even if radiation pressure and energy density are negligible, and that in an atmosphere of low density (e.g., at high altitude) the radiative broadening of the shock front may be sufficiently great to virtually nullify the shock. This effect may play an important role in shock propagation, particularly at high altitudes. In the present calculations, only the end conditions for the transition of the fluid through the shock are involved and it is assumed that the three conservation laws apply just as if the shock front were a true discontinuity.

5. DISCUSSION OF RESULTS

The atmospheric conditions for each altitude considered are presented in table I. The values of the density, pressure, temperature, and sound speed for the undisturbed air at each altitude were taken from the ARDC model atmosphere (1956) contained in reference 4. This "standard atmosphere" which is based on Rocket Panel data has been accepted by the NACA for altitudes up to 100,000 feet and tentatively up to 300,000 feet. The analysis of Minitrack data on the first USSR satellite 1957 alpha 2, by I. Harris and R. Jastrow of the U.S. Naval Research Laboratory indicates that the ARDC model underestimates the atmospheric density for altitudes above 200 kilometers (km). This is well beyond the altitude range of the present calculations which is from sea level to 300,000 feet (91.4 km).

The values for the specific internal energy given in table I were obtained from the National Bureau of Standards equation of state data (reference 1) under the assumption that the composition of the atmosphere is the same for each of the altitudes considered here as at sea level. Approximate equality of the atomic composition is believed to exist at these altitudes as a result of atmospheric convection. However, the

molecular composition changes with altitude due to dissociation, formation of ozone, etc. Wulf and Deming have reported that the dissociation of oxygen begins at 80 km and is essentially complete at 100 km, the transition layer rising 20 km at night; in contrast, Majumdar reported the corresponding altitudes to be 130 km and 167 km.* The present calculations are based on the assumption that only the thermodynamic state of the atmosphere varies with altitude, not the molecular or atomic composition.

Tables II through VIII contain the normal shock relations in tabular form for altitudes ranging from sea level to 300,000 feet in 50,000 foot intervals. The sea-level values (table II) are for a range of shock temperatures from 288.16°K to 316,228°K. The values for all other altitudes considered are for a range from 2000°K to 316,228°K or to the temperature at which the radiation pressure and energy density are approximately 10% of the pressure and energy density of the material (air), when the latter is the lower. Radiation corrections were not included. For each shock temperature, the tables give the corresponding value of the ratio of shock density to ambient density, ρ_s/ρ_o ; the ratio of (absolute) shock pressure to ambient pressure, P_s/P_O; the ratio of shock velocity to ambient speed of sound, U/c_O; the ratio of shock temperature to ambient temperature, T_s/T_O; the effective ratio of specific heats, γ_s , defined by equation (6); the specific internal energy at the shock front, E_s, expressed in calories/gram; and the shock overpressure, P_s-P_O, expressed in pounds per square inch.

The dimensionless variables U/c_O, T_s/T_O, ρ_s/ρ_o , γ_s , and E_s/E_O are shown as functions of P_s/P_O in figures I through V for various altitudes in the range considered here. In the case of weak to moderately strong shocks, air does not deviate greatly from perfect gas behavior and, consequently, the functional relationships between pairs of these dimensionless variables are relatively insensitive to altitude variation. Only the

* See reference 7, page 212, and the appropriate references contained therein.

sea level values for shock temperatures below 2000°K are included in this report. Calculations in this temperature range are now being completed and will be made available in a subsequent report. In the case of strong shocks (i.e., $P_s \gg P_0$), some of the relations are quite sensitive to altitude (as was pointed out in Section 2): the relation between U/c_0 and P_s/P_0* and the one between E_s/E_0 and P_s/P_0 are only slightly affected by the altitude variations considered here; the relation between T_s/T_0 and P_s/P_0, the one between ρ_s/ρ_0 and P_s/P_0, and the one between γ_s and P_s/P_0 are much more sensitive to altitude. This can be seen clearly in the illustrations.

A procedure for obtaining the tabular shock relations for ambient conditions which differ by a moderate amount from those given in table I (e.g., for intermediate altitudes or for somewhat different ambient conditions at sea level) is the following: assume that the tabular values in dimensionless form given in this report for the ambient conditions most nearly equal to the desired ones are valid for the latter and use them accordingly. The validity and the shortcomings of this procedure can be inferred from the illustrations.

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* It was noted by L. Rudlin (reference 8) that this relation is expected to be independent of ambient conditions insofar as the Sachs scaling procedure is valid. Figure I illustrates the remarkable extent to which the relation is insensitive to altitude variation.

LIST OF SYMBOLS

1, 2	subscripts which denote two thermodynamic states defined by the shock temperature, T_s, and the density ρ_1 or ρ_2, the density values nearest the shock density, ρ_s, in the tables of references 2 and 3, one being slightly larger and the other slightly smaller.
a	constant in the expression for the radiation energy density (aT^4)
c	sound speed
C_p	specific heat at constant pressure
C_v	specific heat at constant volume
E	internal energy per unit mass
F	defined by equation (31)
o	subscript refering to the unshocked side of the shock front
P	pressure
R	constant reference value of the gas constant per unit mass
s	subscript refering to the shocked side of the shock front
T	temperature in degrees Kelvin
u	particle velocity
U	shock velocity
x	defined by equation (28)
y	defined by equation (27)
Z	compressibility factor defined by equation (15)
γ	effective ratio of specific heats defined by equations (4) and (6)
ρ	density

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7. Kuiper, Gerard P., The Atmospheres of the Earth and Planets, The University of Chicago Press, Chicago, Illinois, 1948.

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TABLE I ATMOSPHERIC CONDITIONS (ARDC MODEL ATMOSPHERE)

Altitude feet	Temperature °K	Pressure Atmospheres	Density gm per cc	Energy cal per gm	Sound Speed meters per sec.
Sea level	288.16	1.0000 00	1.2250 -03	49.14	340.29
50,000	216.66	1.1511 -01	1.8755 -04	36.94	295.07
100,000	232.67	1.0911 -02	1.6549 -05	39.61	305.77
150,000	277.84	1.4460 -03	1.8369 -06	47.43	334.14
200,000	253.87	2.2464 -04	3.1236 -07	43.32	319.41
250,000	196.86	2.2982 -05	4.1209 -08	33.57	281.26
300,000	197.36	1.7481 -06	3.1178 -09	33.65	281.26

TABLE II NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K	P_s-P_o, psi	P_s/P_o	U/c_o
2.882 2	0.000	1.000 0	1.000 0
2.900 2	3.207 -1	1.021 0	1.003 0
3.000 2	2.204 0	1.149 0	1.061 0
3.100 2	4.232 0	1.288 0	1.116 0
3.200 2	6.391 0	1.434 0	1.171 0
3.300 2	8.666 0	1.585 0	1.227 0
3.400 2	1.104 1	1.751 0	1.282 0
3.500 2	1.351 1	1.919 0	1.337 0
3.600 2	1.606 1	2.092 0	1.391 0
3.700 2	1.867 1	2.270 0	1.445 0
3.800 2	2.134 1	2.452 0	1.498 0
3.900 2	2.407 1	2.637 0	1.550 0
4.000 2	2.683 1	2.826 0	1.601 0
4.100 2	2.964 1	3.017 0	1.651 0
4.200 2	3.248 1	3.210 0	1.701 0
4.300 2	3.535 1	3.405 0	1.749 0
4.400 2	3.824 1	3.602 0	1.796 0
4.500 2	4.116 1	3.801 0	1.843 0
4.600 2	4.410 1	4.001 0	1.889 0
4.700 2	4.707 1	4.203 0	1.934 0
4.800 2	5.006 1	4.406 0	1.978 0
4.900 2	5.307 1	4.611 0	2.022 0
5.000 2	5.609 1	4.816 0	2.065 0
5.100 2	5.912 1	5.023 0	2.107 0
5.200 2	6.218 1	5.231 0	2.149 0
5.300 2	6.525 1	5.440 0	2.190 0
5.400 2	6.833 1	5.649 0	2.230 0
5.500 2	7.143 1	5.860 0	2.270 0
5.600 2	7.453 1	6.072 0	2.309 0
5.700 2	7.765 1	6.233 0	2.348 0
5.800 2	8.078 1	6.497 0	2.386 0
5.900 2	8.393 1	6.711 0	2.424 0
6.000 2	8.709 1	6.926 0	2.461 0
6.100 2	9.026 1	7.142 0	2.498 0
6.200 2	9.344 1	7.358 0	2.535 0
6.300 2	9.664 1	7.576 0	2.571 0
6.400 2	9.985 1	7.794 0	2.606 0

Note: The power of ten is shown after each number.

TABLE II NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K		P_s-P_0, psi		P_s/P_0		U/c_0	
6.500	2	1.030	2	8.013	0	2.642	0
6.600	2	1.062	2	8.233	0	2.677	0
6.700	2	1.095	2	8.453	0	2.711	0
6.800	2	1.127	2	8.674	0	2.745	0
6.900	2	1.160	2	8.895	0	2.779	0
7.000	2	1.192	2	9.117	0	2.813	0
7.100	2	1.225	2	9.340	0	2.846	0
7.200	2	1.258	2	9.564	0	2.879	0
7.300	2	1.291	2	9.786	0	2.911	0
7.400	2	1.324	2	1.001	1	2.944	0
7.500	2	1.358	2	1.024	1	2.977	0
7.600	2	1.391	2	1.047	1	3.009	0
7.700	2	1.425	2	1.070	1	3.041	0
7.800	2	1.459	2	1.093	1	3.073	0
7.900	2	1.493	2	1.116	1	3.104	0
8.000	2	1.527	2	1.139	1	3.135	0
8.500	2	1.698	2	1.255	1	3.288	0
9.000	2	1.871	2	1.373	1	3.435	0
9.500	2	2.046	2	1.492	1	3.577	0
1.000	3	2.223	2	1.613	1	3.715	0
1.050	3	2.402	2	1.734	1	3.849	0
1.100	3	2.582	2	1.857	1	3.979	0
1.150	3	2.764	2	1.981	1	4.106	0
1.200	3	2.947	2	2.105	1	4.230	0
1.250	3	3.132	2	2.231	1	4.352	0
1.300	3	3.318	2	2.358	1	4.470	0
1.350	3	3.506	2	2.486	1	4.587	0
1.400	3	3.695	2	2.614	1	4.701	0
1.450	3	3.886	2	2.744	1	4.814	0
1.500	3	4.07[illegible]	2	2.874	1	4.924	0
1.550	3	4.263	2	3.004	1	5.032	0
1.600	3	4.465	2	3.139	1	5.140	0
1.650	3	4.662	2	3.272	1	5.245	0
1.700	3	4.860	2	3.407	1	5.350	0
1.750	3	5.060	2	3.543	1	5.452	0
1.800	3	5.261	2	3.680	1	5.554	0
1.850	3	5.460	2	3.815	1	5.653	0
1.900	3	5.667	2	3.956	1	5.753	0
1.950	3	5.875	2	4.097	1	5.853	0
2.000	3	6.084	2	4.240	1	5.951	0

TABLE II NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K		P_s-P_o, psi		P_s/P_o		U/c_o	
2.000	3	6.142	2	4.279	1	5.969	0
2.200	3	6.993	2	4.858	1	6.350	0
2.400	3	7.878	2	5.461	1	6.722	0
2.600	3	8.799	2	6.087	1	7.086	0
2.800	3	9.757	2	6.739	1	7.445	0
3.000	3	1.076	3	7.423	1	7.802	0
3.200	3	1.183	3	8.152	1	8.163	0
3.400	3	1.297	3	8.929	1	8.530	0
3.600	3	1.419	3	9.759	1	8.903	0
3.800	3	1.552	3	1.066	2	9.290	0
4.000	3	1.687	3	1.158	2	9.670	0
4.200	3	1.832	3	1.256	2	1.005	1
4.400	3	1.982	3	1.359	2	1.044	1
4.600	3	2.137	3	1.464	2	1.083	1
4.800	3	2.294	3	1.571	2	1.121	1
5.000	3	2.452	3	1.678	2	1.158	1
5.500	3	2.841	3	1.943	2	1.244	1
6.000	3	3.226	3	2.205	2	1.324	1
6.500	3	3.621	3	2.474	2	1.402	1
7.000	3	4.048	3	2.764	2	1.481	1
7.500	3	4.534	3	3.095	2	1.566	1
8.000	3	5.100	3	3.480	2	1.658	1
8.500	3	5.765	3	3.933	2	1.760	1
9.000	3	6.533	3	4.455	2	1.870	1
9.500	3	7.396	3	5.042	2	1.987	1
1.000	4	8.347	3	5.690	2	2.108	1
1.100	4	1.041	4	7.100	2	2.350	1
1.200	4	1.253	4	8.538	2	2.576	1
1.300	4	1.449	4	9.870	2	2.769	1
1.400	4	1.619	4	1.102	3	2.928	1
1.500	4	1.766	4	1.203	3	3.061	1

Different equation of state tables were used in obtaining the two slightly differing sets of results for 2000°K.

TABLE II NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K		$P_s - P_0$, psi		P_s/P_0		U/c_0	
1.585	4	1.951	4	1.328	3	3.218	1
1.778	4	2.159	4	1.470	3	3.391	1
1.995	4	2.449	4	1.668	3	3.615	1
2.239	4	2.848	4	1.939	3	3.900	1
2.512	4	3.379	4	2.300	3	4.248	1
3.162	4	4.841	4	3.295	3	5.086	1
3.548	4	5.697	4	3.877	3	5.523	1
3.981	4	6.632	4	4.513	3	5.965	1
4.467	4	7.677	4	5.225	3	6.426	1
5.012	4	8.964	4	6.100	3	6.949	1
5.623	4	1.065	5	7.248	3	7.576	1
6.310	4	1.276	5	8.683	3	8.293	1
7.080	4	1.533	5	1.043	4	9.095	1
7.943	4	1.835	5	1.248	4	9.954	1
8.913	4	2.192	5	1.491	4	1.088	2
1.000	5	2.625	5	1.786	4	1.192	2
1.122	5	3.148	5	2.142	4	1.306	2
1.259	5	3.769	5	2.565	4	1.430	2
1.412	5	4.493	5	3.057	4	1.563	2
1.585	5	5.357	5	3.645	4	1.709	2
1.778	5	6.351	5	4.322	4	1.863	2
1.995	5	7.488	5	5.095	4	2.025	2
2.239	5	8.742	5	5.948	4	2.192	2
2.512	5	1.012	6	6.888	4	2.363	2
2.818	5	1.154	6	7.854	4	2.530	2
3.162	5	1.296	6	8.819	4	2.689	2

TABLE II NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K		T_s/T_o		ρ_s/ρ_o		E_s cal/gm		γ_s
2.882	2	1.000	0	1.000	0	4.91	1	1.402
2.900	2	1.006	0	1.015	0	4.94	1	1.402
3.000	2	1.041	0	1.105	0	5.11	1	1.402
3.100	2	1.075	0	1.197	0	5.28	1	1.402
3.200	2	1.110	0	1.292	0	5.45	1	1.402
3.300	2	1.145	0	1.388	0	5.62	1	1.402
3.400	2	1.179	0	1.484	0	5.80	1	1.402
3.500	2	1.214	0	1.580	0	5.97	1	1.402
3.600	2	1.249	0	1.674	0	6.14	1	1.402
3.700	2	1.284	0	1.767	0	6.31	1	1.402
3.800	2	1.318	0	1.858	0	6.48	1	1.402
3.900	2	1.353	0	1.947	0	6.66	1	1.402
4.000	2	1.388	0	2.034	0	6.83	1	1.402
4.100	2	1.422	0	2.118	0	7.00	1	1.401
4.200	2	1.457	0	2.200	0	7.18	1	1.401
4.300	2	1.492	0	2.279	0	7.35	1	1.401
4.400	2	1.526	0	2.356	0	7.53	1	1.401
4.500	2	1.561	0	2.431	0	7.70	1	1.401
4.600	2	1.596	0	2.503	0	7.88	1	1.401
4.700	2	1.631	0	2.573	0	8.05	1	1.401
4.800	2	1.665	0	2.641	0	8.23	1	1.400
4.900	2	1.700	0	2.707	0	8.40	1	1.400
5.000	2	1.735	0	2.771	0	8.58	1	1.400
5.100	2	1.769	0	2.832	0	8.76	1	1.400
5.200	2	1.804	0	2.893	0	8.94	1	1.400
5.300	2	1.839	0	2.951	0	9.11	1	1.399
5.400	2	1.873	0	3.008	0	9.29	1	1.399
5.500	2	1.908	0	3.063	0	9.47	1	1.399
5.600	2	1.943	0	3.116	0	9.65	1	1.399
5.700	2	1.978	0	3.169	0	9.83	1	1.398
5.800	2	2.012	0	3.219	0	1.00	2	1.398
5.900	2	2.047	0	3.269	0	1.02	2	1.398
6.000	2	2.082	0	3.317	0	1.03	2	1.397
6.100	2	2.116	0	3.364	0	1.05	2	1.397
6.200	2	2.151	0	3.410	0	1.07	2	1.397
6.300	2	2.186	0	3.454	0	1.09	2	1.396
6.400	2	2.220	0	3.498	0	1.11	2	1.396

TABLE II   NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K		T_s/T_0		ρ_s/ρ_0		E_s cal/gm		γ_s
6.500	2	2.255	0	3.541	0	1.13	2	1.396
6.600	2	2.290	0	3.582	0	1.14	2	1.395
6.700	2	2.325	0	3.623	0	1.16	2	1.395
6.800	2	2.359	0	3.662	0	1.18	2	1.395
6.900	2	2.394	0	3.701	0	1.20	2	1.394
7.000	2	2.429	0	3.739	0	1.22	2	1.394
7.100	2	2.463	0	3.777	0	1.24	2	1.393
7.200	2	2.498	0	3.813	0	1.26	2	1.393
7.300	2	2.533	0	3.849	0	1.28	2	1.392
7.400	2	2.568	0	3.884	0	1.29	2	1.392
7.500	2	2.602	0	3.918	0	1.31	2	1.392
7.600	2	2.637	0	3.952	0	1.33	2	1.391
7.700	2	2.672	0	3.985	0	1.35	2	1.391
7.800	2	2.706	0	4.018	0	1.37	2	1.391
7.900	2	2.741	0	4.050	0	1.39	2	1.390
8.000	2	2.776	0	4.081	0	1.41	2	1.390
8.500	2	2.949	0	4.229	0	1.51	2	1.388
9.000	2	3.123	0	4.366	0	1.61	2	1.386
9.500	2	3.296	0	4.492	0	1.71	2	1.384
1.000	3	3.470	0	4.610	0	1.81	2	1.381
1.050	3	3.643	0	4.720	0	1.91	2	1.379
1.100	3	3.817	0	4.822	0	2.01	2	1.377
1.150	3	3.990	0	4.919	0	2.12	2	1.374
1.200	3	4.164	0	5.010	0	2.23	2	1.372
1.250	3	4.337	0	5.098	0	2.33	2	1.370
1.300	3	4.511	0	5.179	0	2.44	2	1.368
1.350	3	4.684	0	5.258	0	2.55	2	1.365
1.400	3	4.858	0	5.334	0	2.66	2	1.363
1.450	3	5.031	0	5.405	0	2.77	2	1.361
1.500	3	5.205	0	5.474	0	2.88	2	1.359
1.550	3	5.378	0	5.535	0	3.00	2	1.357
1.600	3	5.552	0	5.605	0	3.11	2	1.355
1.650	3	5.725	0	5.666	0	3.23	2	1.353
1.700	3	5.899	0	5.727	0	3.34	2	1.351
1.750	3	6.073	0	5.786	0	3.46	2	1.349
1.800	3	6.246	0	5.843	0	3.58	2	1.347
1.850	3	6.420	0	5.899	0	3.70	2	1.345
1.900	3	6.593	0	5.953	0	3.82	2	1.343
1.950	3	6.767	0	6.007	0	3.94	2	1.341
2.000	3	6.940	0	6.059	0	4.07	2	1.340

TABLE II NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K		T_s/T_0		ρ_s/ρ_0		E_s cal/gm		γ_s
2.000	3	6.941	0	6.166	0	4.09	2	1.335
2.200	3	7.635	0	6.364	0	4.59	2	1.328
2.400	3	8.329	0	6.556	0	5.12	2	1.321
2.600	3	9.023	0	6.743	0	5.67	2	1.314
2.800	3	9.717	0	6.927	0	6.25	2	1.307
3.000	3	1.041	1	7.112	0	6.85	2	1.301
3.200	3	1.110	1	7.306	0	7.50	2	1.294
3.400	3	1.180	1	7.508	0	8.20	2	1.286
3.600	3	1.249	1	7.715	0	8.95	2	1.279
3.800	3	1.319	1	7.939	0	9.77	2	1.272
4.000	3	1.388	1	8.136	0	1.06	3	1.265
4.200	3	1.458	1	8.339	0	1.14	3	1.259
4.400	3	1.527	1	8.528	0	1.24	3	1.253
4.600	3	1.596	1	8.701	0	1.33	3	1.248
4.800	3	1.666	1	8.853	0	1.43	3	1.244
5.000	3	1.735	1	8.983	0	1.53	3	1.241
5.500	3	1.909	1	9.215	0	1.77	3	1.235
6.000	3	2.082	1	9.365	0	2.00	3	1.232
6.500	3	2.256	1	9.480	0	2.23	3	1.230
7.000	3	2.429	1	9.634	0	2.50	3	1.227
7.500	3	2.603	1	9.842	0	2.80	3	1.222
8.000	3	2.776	1	1.010	1	3.15	3	1.216
8.500	3	2.950	1	1.042	1	3.56	3	1.209
9.000	3	3.123	1	1.077	1	4.05	3	1.202
9.500	3	3.297	1	1.112	1	4.59	3	1.195
1.000	4	3.470	1	1.144	1	5.20	3	1.189
1.100	4	3.817	1	1.195	1	6.51	3	1.180
1.200	4	4.164	1	1.220	1	7.83	3	1.176
1.300	4	4.511	1	1.224	1	9.05	3	1.176
1.400	4	4.858	1	1.213	1	1.00	4	1.178
1.500	4	5.205	1	1.[illegible]96	1	1.09	4	1.181

TABLE II NORMAL SHOCK RELATIONS AT SEA LEVEL

T_s °K	T_s/T_o	ρ_s/ρ_o	E_s cal/gm	γ_s
1.585 4	5.500 1	1.185 1	1.20 4	1.183
1.778 4	6.171 1	1.146 1	1.33 4	1.191
1.995 4	6.924 1	1.122 1	1.50 4	1.195
2.239 4	7.769 1	1.112 1	1.74 4	1.197
2.512 4	8.717 1	1.110 1	2.07 4	1.198
3.162 4	1.097 2	1.105 1	2.96 4	1.199
3.548 4	1.231 2	1.084 1	3.48 4	1.203
3.981 4	1.382 2	1.061 1	4.04 4	1.208
4.467 4	1.550 2	1.037 1	4.67 4	1.213
5.012 4	1.739 2	1.022 1	5.45 4	1.216
5.623 4	1.951 2	1.017 1	6.47 4	1.217
6.310 4	2.190 2	1.016 1	7.76 4	1.217
7.080 4	2.457 2	1.012 1	9.32 4	1.218
7.943 4	2.757 2	1.002 1	1.11 5	1.221
8.913 4	3.093 2	9.906 0	1.33 5	1.224
1.000 5	3.470 2	9.801 0	1.59 5	1.226
1.122 5	3.894 2	9.681 0	1.90 5	1.229
1.259 5	4.369 2	9.546 0	2.28 5	1.233
1.412 5	4.902 2	9.384 0	2.71 5	1.237
1.585 5	5.500 2	9.228 0	3.23 5	1.241
1.778 5	6.171 2	9.043 0	3.82 5	1.247
1.995 5	6.924 2	8.842 0	4.49 5	1.253
2.239 5	7.769 2	8.615 0	5.23 5	1.261
2.512 5	8.717 2	8.370 0	6.03 5	1.270
2.818 5	9.781 2	8.088 0	6.84 5	1.281
3.162 5	1.097 3	7.761 0	7.62 5	1.294

TABLE III NORMAL SHOCK RELATIONS AT 50,000 FEET

T_s °K		P_s-P_o, psi		P_s/P_o		U/c_o	
2.000	3	9.717	1	5.843	1	6.980	0
2.200	3	1.103	2	6.623	1	7.418	0
2.400	3	1.241	2	7.439	1	7.848	0
2.600	3	1.388	2	8.308	1	8.279	0
2.800	3	1.546	2	9.242	1	8.715	0
3.000	3	1.719	2	1.026	2	9.164	0
3.200	3	1.911	2	1.140	2	9.638	0
3.400	3	2.126	2	1.266	2	1.013	1
3.600	3	2.363	2	1.407	2	1.065	1
3.800	3	2.627	2	1.563	2	1.120	1
4.000	3	2.894	2	1.720	2	1.174	1
4.200	3	3.177	2	1.888	2	1.227	1
4.400	3	3.462	2	2.056	2	1.279	1
4.600	3	3.742	2	2.222	2	1.329	1
4.800	3	4.013	2	2.382	2	1.375	1
5.000	3	4.274	2	2.536	2	1.418	1
5.500	3	4.888	2	2.899	2	1.515	1
6.000	3	5.520	2	3.273	2	1.609	1
6.500	3	6.255	2	3.707	2	1.711	1
7.000	3	7.169	2	4.247	2	1.829	1
7.500	3	8.306	2	4.920	2	1.964	1
8.000	3	9.699	2	5.743	2	2.118	1
8.500	3	1.133	3	6.708	2	2.284	1
9.000	3	1.315	3	7.788	2	2.457	1
9.500	3	1.510	3	8.936	2	2.629	1
1.000	4	1.707	3	1.010	3	2.793	1
1.100	4	2.069	3	1.224	3	3.073	1
1.200	4	2.359	3	1.395	3	3.282	1
1.300	4	2.590	3	1.532	3	3.442	1
1.400	4	2.797	3	1.654	3	3.580	1
1.500	4	3.005	3	1.777	3	3.714	1

TABLE III NORMAL SHOCK RELATIONS AT 50,000 FEET

T_s °K	P_s-P_o, psi	P_s/P_o	U/a_o
1.585 4	3.199 3	1.892 3	3.835 1
1.778 4	3.695 3	2.185 3	4.124 1
1.995 4	4.399 3	2.601 3	4.501 1
2.239 4	5.345 3	3.160 3	4.963 1
2.512 4	6.522 3	3.856 3	5.484 1
3.162 4	9.253 3	5.470 3	6.548 1
3.548 4	1.060 4	6.271 3	7.025 1
3.981 4	1.215 4	7.188 3	7.533 1
4.467 4	1.425 4	8.429 3	8.162 1
5.012 4	1.721 4	1.017 4	8.966 1
5.623 4	2.100 4	1.241 4	9.903 1
6.310 4	2.538 4	1.500 4	1.088 2
7.080 4	3.033 4	1.793 4	1.191 2
7.943 4	3.635 4	2.149 4	1.304 2
8.913 4	4.383 4	2.591 4	1.432 2
1.000 5	5.288 4	3.126 4	1.574 2
1.122 5	6.336 4	3.745 4	1.724 2
1.259 5	7.568 4	4.473 4	1.885 2
1.413 5	8.986 4	5.312 4	2.056 2
1.585 5	1.069 5	6.324 4	2.245 2
1.778 5	1.254 5	7.414 4	2.434 2
1.995 5	1.453 5	8.593 4	2.625 2
2.239 5	1.656 5	9.791 4	2.808 2
2.512 5	1.857 5	1.098 5	2.982 2
2.818 5	2.047 5	1.210 5	3.141 2
3.162 5	2.263 5	1.337 5	3.314 2

TABLE III NORMAL SHOCK RELATIONS AT 50,000 FEET

T_s °K		T_s/T_o		ρ_s/ρ_o		E_s cal/gm		γ_s
2.000	3	9.231	0	6.330	1	4.09	2	1.335
2.200	3	1.015	1	6.522	1	4.60	2	1.328
2.400	3	1.108	1	6.712	1	5.13	2	1.320
2.600	3	1.200	1	6.912	1	5.71	2	1.312
2.800	3	1.292	1	7.126	1	6.33	2	1.304
3.000	3	1.385	1	7.360	1	7.02	2	1.295
3.200	3	1.477	1	7.626	1	7.79	2	1.285
3.400	3	1.569	1	7.916	1	8.66	2	1.274
3.600	3	1.662	1	8.223	1	9.62	2	1.264
3.800	3	1.754	1	8.547	1	1.07	3	1.254
4.000	3	1.846	1	8.822	1	1.17	3	1.246
4.200	3	1.939	1	9.083	1	1.29	3	1.239
4.400	3	2.031	1	9.301	1	1.41	3	1.233
4.600	3	2.123	1	9.473	1	1.52	3	1.229
4.800	3	2.215	1	9.601	1	1.63	3	1.226
5.000	3	2.308	1	9.692	1	1.73	3	1.224
5.500	3	2.539	1	9.820	1	1.98	3	1.221
6.000	3	2.769	1	9.944	1	2.23	3	1.219
6.500	3	3.000	1	1.016	2	2.53	3	1.214
7.000	3	3.231	1	1.050	2	2.90	3	1.207
7.500	3	3.462	1	1.095	2	3.36	3	1.198
8.000	3	3.692	1	1.147	2	3.94	3	1.188
8.500	3	3.923	1	1.201	2	4.62	3	1.179
9.000	3	4.154	1	1.249	2	5.38	3	1.172
9.500	3	4.385	1	1.287	2	6.19	3	1.166
1.000	4	4.616	1	1.314	2	7.01	3	1.163
1.100	4	5.077	1	1.333	2	8.49	3	1.161
1.200	4	5.539	1	1.320	2	9.65	3	1.163
1.300	4	6.000	1	1.294	2	1.05	4	1.166
1.400	4	6.462	1	1.267	2	1.13	4	1.170
1.500	4	6.923	1	1.244	2	1.22	4	1.174

TABLE III NORMAL SHOCK RELATIONS AT 50,000 FEET

T_s °K		T_s/T_0		ρ_s/ρ_0		E_s cal/gm		γ_s
1.585	4	7.315	1	1.228	1	1.29	4	1.176
1.778	4	8.208	1	1.207	1	1.49	4	1.180
1.995	4	9.209	1	1.199	1	1.78	4	1.181
2.239	4	1.033	2	1.194	1	2.16	4	1.182
2.512	4	1.159	2	1.183	1	2.63	4	1.184
3.162	4	1.460	2	1.126	1	3.71	4	1.194
3.548	4	1.638	2	1.080	1	4.23	4	1.204
3.981	4	1.837	2	1.048	1	4.84	4	1.210
4.467	4	2.062	2	1.035	1	5.67	4	1.213
5.012	4	2.313	2	1.039	1	6.85	4	1.212
5.623	4	2.595	2	1.042	1	8.36	4	1.211
6.310	4	2.912	2	1.038	1	1.01	5	1.212
7.080	4	3.268	2	1.027	1	1.20	5	1.215
7.943	4	3.666	2	1.020	1	1.44	5	1.216
8.913	4	4.114	2	1.016	1	1.74	5	1.217
1.000	5	4.616	2	1.010	1	2.10	5	1.219
1.122	5	5.179	2	1.000	1	2.51	5	1.221
1.259	5	5.811	2	9.880	0	3.00	5	1.224
1.412	5	6.520	2	9.717	0	3.55	5	1.228
1.585	5	7.315	2	9.589	0	4.22	5	1.232
1.778	5	8.208	2	9.374	0	4.94	5	1.238
1.995	5	9.209	2	9.122	0	5.71	5	1.245
2.239	5	1.033	3	8.808	0	6.47	5	1.255
2.512	5	1.159	3	8.463	0	7.22	5	1.267
2.818	5	1.301	3	8.079	0	7.90	5	1.282
3.162	5	1.460	3	7.687	0	8.51	5	1.304

TABLE IV NORMAL SHOCK RELATIONS AT 100,000 FEET

T_s °K		P_s-P_0, psi		P_s/P_0		U/c_0	
2.000	3	8.507	0	5.405	1	6.713	0
2.200	3	9.703	0	6.151	1	7.148	0
2.400	3	1.100	1	6.964	1	7.589	0
2.600	3	1.249	1	7.889	1	8.056	0
2.800	3	1.423	1	8.977	1	8.566	0
3.000	3	1.631	1	1.027	2	9.131	0
3.200	3	1.878	1	1.181	2	9.757	0
3.400	3	2.163	1	1.358	2	1.042	1
3.600	3	2.471	1	1.551	2	1.110	1
3.800	3	2.793	1	1.751	2	1.177	1
4.000	3	3.085	1	1.933	2	1.235	1
4.200	3	3.357	1	2.103	2	1.288	1
4.400	3	3.600	1	2.255	2	1.333	1
4.600	3	3.821	1	2.393	2	1.373	1
4.800	3	4.029	1	2.523	2	1.410	1
5.000	3	4.239	1	2.654	2	1.446	1
5.500	3	4.840	1	3.028	2	1.543	1
6.000	3	5.668	1	3.545	2	1.667	1
6.500	3	6.829	1	4.269	2	1.824	1
7.000	3	8.374	1	5.232	2	2.013	1
7.500	3	1.028	2	6.425	2	2.225	1
8.000	3	1.242	2	7.758	2	2.440	1
8.500	3	1.458	2	9.106	2	2.641	1
9.000	3	1.655	2	1.033	3	2.812	1
9.500	3	1.820	2	1.136	3	2.949	1
1.000	4	1.952	2	1.218	3	3.055	1
1.100	4	2.157	2	1.346	3	3.215	1
1.200	4	2.345	2	1.463	3	3.355	1
1.300	4	2.560	2	1.597	3	3.508	1
1.400	4	2.822	2	1.761	3	3.685	1
1.500	4	3.126	2	1.950	3	3.880	1

TABLE IV NORMAL SHOCK RELATIONS AT 100,000 FEET

T_s °K	P_s-P_o, psi	P_s/P_o	U/c_o
1.585 4	3.441 2	2.147 3	4.070 1
1.778 4	4.305 2	2.686 3	4.551 1
1.995 4	5.427 2	3.385 3	5.110 1
2.239 4	6.680 2	4.166 3	5.674 1
2.512 4	7.856 2	4.900 3	6.164 1
2.818 4	8.851 2	5.521 3	6.558 1
3.162 4	9.907 2	6.179 3	6.950 1
3.548 4	1.139 3	7.108 3	7.463 1
3.981 4	1.391 3	8.679 3	8.243 1
4.467 4	1.736 3	1.082 4	9.202 1
5.012 4	2.116 3	1.320 4	1.016 2
5.623 4	2.504 3	1.561 4	1.106 2
6.310 4	2.983 3	1.860 4	1.207 2
7.080 4	3.623 3	2.262 4	1.331 2
7.943 4	4.412 3	2.752 4	1.469 2
8.913 4	5.290 3	3.299 4	1.609 2
1.000 5	6.354 3	3.963 4	1.764 2
1.122 5	7.622 3	4.753 4	1.933 2
1.259 5	9.042 3	5.639 4	2.107 2
1.412 5	1.064 4	6.635 4	2.288 2
1.585 5	1.238 4	7.725 4	2.471 2
1.778 5	1.399 4	8.728 4	2.632 2
1.993 5	1.547 4	9.651 4	2.775 2
2.239 5	1.682 4	1.049 5	2.903 2
2.512 5	1.804 4	1.125 5	3.017 2
2.818 5	1.924 4	1.200 5	3.128 2
3.162 5	2.034 4	1.269 5	3.231 2

TABLE IV NORMAL SHOCK RELATIONS AT 100,000 FEET

T_s °K	T_s/T_o	ρ_s/ρ_o	E_s cal/gm	γ_s
2.000 3	8.596 0	6.289 0	4.096 2	1.335
2.200 3	9.455 0	6.503 0	4.623 2	1.327
2.400 3	1.032 1	6.739 0	5.202 2	1.317
2.600 3	1.117 1	7.025 0	5.870 2	1.305
2.800 3	1.203 1	7.376 0	6.663 2	1.291
3.000 3	1.289 1	7.798 0	7.616 2	1.276
3.200 3	1.375 1	8.289 0	8.767 2	1.260
3.400 3	1.461 1	8.807 0	1.009 3	1.244
3.600 3	1.547 1	9.295 0	1.153 3	1.231
3.800 3	1.633 1	9.720 0	1.304 3	1.221
4.000 3	1.719 1	9.994 0	1.438 3	1.215
4.200 3	1.805 1	1.017 1	1.564 3	1.211
4.400 3	1.891 1	1.027 1	1.674 3	1.209
4.600 3	1.977 1	1.030 1	1.774 3	1.209
4.800 3	2.063 1	1.032 1	1.868 3	1.209
5.000 3	2.149 1	1.034 1	1.962 3	1.209
5.500 3	2.364 1	1.050 1	2.237 3	1.206
6.000 3	2.579 1	1.095 1	2.622 3	1.197
6.500 3	2.794 1	1.165 1	3.166 3	1.185
7.000 3	3.009 1	1.251 1	3.891 3	1.172
7.500 3	3.223 1	1.339 1	4.805 3	1.159
8.000 3	3.438 1	1.412 1	5.825 3	1.151
8.500 3	3.653 1	1.459 1	6.848 3	1.145
9.000 3	3.868 1	1.480 1	7.769 3	1.143
9.500 3	4.083 1	1.480 1	8.527 3	1.144
1.000 4	4.298 1	1.467 1	9.129 3	1.145
1.100 4	4.728 1	1.425 1	1.005 4	1.150
1.200 4	5.158 1	1.387 1	1.089 4	1.154
1.300 4	5.587 1	1.363 1	1.187 4	1.157
1.400 4	6.017 1	1.351 1	1.308 4	1.159
1.500 4	6.447 1	1.341 1	1.448 4	1.160

TABLE IV NORMAL SHOCK RELATIONS AT 100,000 FEET

T_s °K		T_s/T_o		ρ_s/ρ_o		E_s cal/gm		γ_s
1.585	4	6.812	1	1.348	1	1.59	4	1.159
1.778	4	7.643	1	1.356	1	1.99	4	1.158
1.995	4	8.576	1	1.351	1	2.51	4	1.158
2.239	4	9.622	1	1.322	1	3.08	4	1.163
2.512	4	1.080	2	1.270	1	3.61	4	1.170
2.818	4	1.211	2	1.207	1	4.04	4	1.180
3.162	4	1.359	2	1.159	1	4.51	4	1.188
3.548	4	1.525	2	1.132	1	5.18	4	1.193
3.981	4	1.711	2	1.142	1	6.34	4	1.191
4.467	4	1.920	2	1.156	1	7.92	4	1.189
5.012	4	2.154	2	1.152	1	9.65	4	1.189
5.623	4	2.417	2	1.132	1	1.13	5	1.193
6.310	4	2.712	2	1.123	1	1.35	5	1.195
7.080	4	3.043	2	1.126	1	1.65	5	1.194
7.943	4	3.414	2	1.125	1	2.00	5	1.194
8.913	4	3.830	2	1.115	1	2.40	5	1.196
1.000	5	4.298	2	1.108	1	2.88	5	1.198
1.122	5	4.822	2	1.098	1	3.46	5	1.200
1.259	5	5.410	2	1.080	1	4.09	5	1.203
1.412	5	6.071	2	1.058	1	4.81	5	1.208
1.585	5	6.812	2	1.035	1	5.58	5	1.213
1.778	5	7.643	2	9.962	0	6.28	5	1.222
1.993	5	8.564	2	9.514	0	6.90	5	1.234
2.239	5	9.622	2	9.032	0	7.45	5	1.249
2.512	5	1.080	3	8.541	0	7.92	5	1.265
2.818	5	1.211	3	8.069	0	8.39	5	1.283
3.162	5	1.359	3	7.583	0	8.79	5	1.304

TABLE V   NORMAL SHOCK RELATIONS AT 150,000 FEET

T_s °K	$P_s - P_0$, psi	P_s/P_0	U/c_0
2.000 3	9.243 -1	4.449 1	6.088 0
2.200 3	1.067 0	5.121 1	6.515 0
2.400 3	1.237 0	5.925 1	6.983 0
2.600 3	1.456 0	6.953 1	7.530 0
2.800 3	1.741 0	8.293 1	8.180 0
3.000 3	2.096 0	9.967 1	8.921 0
3.200 3	2.505 0	1.189 2	9.702 0
3.400 3	2.925 0	1.386 2	1.044 1
3.600 3	3.307 0	1.566 2	1.108 1
3.800 3	3.630 0	1.718 2	1.160 1
4.000 3	3.882 0	1.837 2	1.199 1
4.200 3	4.104 0	1.941 2	1.233 1
4.400 3	4.317 0	2.041 2	1.265 1
4.600 3	4.545 0	2.149 2	1.298 1
4.800 3	4.806 0	2.271 2	1.332 1
5.000 3	5.117 0	2.418 2	1.376 1
5.500 3	6.221 0	2.937 2	1.512 1
6.000 3	7.955 0	3.753 2	1.703 1
6.500 3	1.035 1	4.883 2	1.935 1
7.000 3	1.322 1	6.235 2	2.181 1
7.500 3	1.611 1	7.594 2	2.403 1
8.000 3	1.851 1	8.724 2	2.575 1
8.500 3	2.025 1	9.543 2	2.694 1
9.000 3	2.152 1	1.013 3	2.778 1
9.500 3	2.257 1	1.063 3	2.847 1
1.000 4	2.359 1	1.111 3	2.913 1
1.100 4	2.601 1	1.225 3	3.061 1
1.200 4	2.931 1	1.380 3	3.251 1
1.300 4	3.375 1	1.589 3	3.487 1
1.400 4	3.939 1	1.854 3	3.766 1
1.500 4	4.611 1	2.171 3	4.073 1

TABLE V NORMAL SHOCK RELATIONS AT 150,000 FEET

T_s °K	P_s-P_0, psi	P_s/P_0	U/c_0
1.585 4	5.218 1	2.456 3	4.332 1
1.778 4	6.690 1	3.149 3	4.906 1
1.995 4	8.058 1	3.793 3	5.391 1
2.239 4	9.073 1	4.270 3	5.732 1
2.512 4	9.872 1	4.646 3	5.994 1
2.818 4	1.095 2	5.157 3	6.326 1
3.162 4	1.316 2	6.197 3	6.934 1
3.548 4	1.669 2	7.858 3	7.801 1
3.981 4	2.092 2	9.847 3	8.729 1
4.467 4	2.480 2	1.167 4	9.512 1
5.012 4	2.886 2	1.358 4	1.027 2
5.623 4	3.489 2	1.642 4	1.129 2
6.310 4	4.320 2	2.033 4	1.255 2
7.080 4	5.196 2	2.445 4	1.377 2
7.943 4	6.208 2	2.921 4	1.506 2
8.913 4	7.534 2	3.545 4	1.659 2
1.000 5	9.029 2	4.249 4	1.817 2
1.122 5	1.069 3	5.031 4	1.979 2
1.259 5	1.256 3	5.912 4	2.147 2
1.413 5	1.429 3	6.726 4	2.294 2
1.585 5	1.577 3	7.422 4	2.416 2
1.778 5	1.707 3	8.035 4	2.521 2
1.995 5	1.819 3	8.563 4	2.611 2
2.239 5	1.924 3	9.056 4	2.695 2
2.512 5	2.032 3	9.566 4	2.781 2

TABLE V NORMAL SHOCK RELATIONS AT 150,000 FEET

T_s °K		T_s/T_o		ρ_s/ρ_o		E_s cal/gm		γ =
2.000	3	7.198	0	6.179	0	4.11	2	1.334
2.200	3	7.918	0	6.455	0	4.68	2	1.328
2.400	3	8.638	0	6.816	0	5.37	2	1.308
2.600	3	9.357	0	7.317	0	6.28	2	1.288
2.800	3	1.007	1	7.977	0	7.47	2	1.265
3.000	3	1.079	1	8.746	0	8.98	2	1.242
3.200	3	1.151	1	9.509	0	1.07	3	1.222
3.400	3	1.223	1	1.013	1	1.24	3	1.209
3.600	3	1.295	1	1.054	1	1.40	3	1.201
3.800	3	1.367	1	1.074	1	1.54	3	1.198
4.000	3	1.439	1	1.078	1	1.64	3	1.197
4.200	3	1.511	1	1.075	1	1.73	3	1.198
4.400	3	1.583	1	1.072	1	1.82	3	1.199
4.600	3	1.655	1	1.073	1	1.91	3	1.199
4.800	3	1.727	1	1.079	1	2.02	3	1.198
5.000	3	1.799	1	1.092	1	2.15	3	1.196
5.500	3	1.979	1	1.162	1	2.61	3	1.184
6.000	3	2.159	1	1.282	1	3.36	3	1.166
6.500	3	2.339	1	1.419	1	4.40	3	1.149
7.000	3	2.519	1	1.535	1	5.63	3	1.137
7.500	3	2.699	1	1.605	1	6.86	3	1.131
8.000	3	2.879	1	1.626	1	7.87	3	1.130
8.500	3	3.059	1	1.613	1	8.59	3	1.131
9.000	3	3.239	1	1.584	1	9.11	3	1.134
9.500	3	3.419	1	1.552	1	9.54	3	1.137
1.000	4	3.599	1	1.524	1	9.96	3	1.139
1.100	4	3.959	1	1.487	1	1.09	4	1.143
1.200	4	4.319	1	1.477	1	1.23	4	1.144
1.300	4	4.678	1	1.487	1	1.42	4	1.143
1.400	4	5.038	1	1.506	1	1.66	4	1.141
1.500	4	5.398	1	1.524	1	1.94	4	1.139

TABLE V NORMAL SHOCK RELATIONS AT 150,000 FEET

T_s °K	T_s/T_o	ρ_s/ρ_o	E_s cal/gm	γ_s
1.585 4	5.704 1	1.532 1	2.20 4	1.138
1.778 4	6.400 1	1.523 1	2.82 4	1.139
1.995 4	7.181 1	1.471 1	3.38 4	1.145
2.239 4	8.057 1	1.390 1	3.79 4	1.154
2.512 4	9.040 1	1.307 1	4.10 4	1.165
2.818 4	1.014 2	1.254 1	4.53 4	1.173
3.162 4	1.138 2	1.260 1	5.45 4	1.172
3.548 4	1.277 2	1.289 1	6.94 4	1.167
3.891 4	1.432 2	1.299 1	8.70 4	1.166
4.467 4	1.607 2	1.274 1	1.02 5	1.170
5.012 4	1.803 2	1.247 1	1.19 5	1.174
5.623 4	2.023 2	1.250 1	1.44 5	1.173
6.310 4	2.270 2	1.261 1	1.79 5	1.171
7.080 4	2.548 2	1.251 1	2.15 5	1.173
7.943 4	2.858 2	1.241 1	2.56 5	1.175
8.913 4	3.207 2	1.240 1	3.11 5	1.175
1.000 5	3.599 2	1.228 1	3.72 5	1.177
1.122 5	4.038 2	1.208 1	4.40 5	1.180
1.259 5	4.531 2	1.184 1	5.16 5	1.184
1.412 5	5.084 2	1.142 1	5.85 5	1.192
1.585 5	5.704 2	1.089 1	6.42 5	1.202
1.778 5	6.400 2	1.031 1	6.91 5	1.215
1.995 5	7.181 2	9.700 0	7.32 5	1.230
2.239 5	8.057 2	9.107 0	7.68 5	1.247
2.512 5	9.040 2	8.561 0	8.05 5	1.264

TABLE VI NORMAL SHOCK RELATIONS AT 200,000 FEET

T_s °K		P_s-P_o, psi		P_s/P_o		U/c_o	
2.000	3	1.606	-1	4.967	1	6.428	0
2.200	3	1.883	-1	5.806	1	6.924	0
2.400	3	2.259	-1	6.944	1	7.531	0
2.600	3	2.791	-1	8.555	1	8.301	0
2.800	3	3.495	-1	1.068	2	9.217	0
3.000	3	4.311	-1	1.316	2	1.017	1
3.200	3	5.111	-1	1.558	2	1.103	1
3.400	3	5.758	-1	1.754	2	1.169	1
3.600	3	6.232	-1	1.897	2	1.216	1
3.800	3	6.606	-1	2.011	2	1.252	1
4.000	3	6.942	-1	2.112	2	1.284	1
4.200	3	7.300	-1	2.221	2	1.317	1
4.400	3	7.724	-1	2.349	2	1.355	1
4.600	3	8.255	-1	2.510	2	1.400	1
4.800	3	8.938	-1	2.717	2	1.455	1
5.000	3	9.814	-1	2.982	2	1.522	1
5.500	3	1.305	0	3.964	2	1.746	1
6.000	3	1.787	0	5.425	2	2.034	1
6.500	3	2.369	0	7.187	2	2.334	1
7.000	3	2.901	0	8.797	2	2.580	1
7.500	3	3.270	0	9.916	2	2.739	1
8.000	3	3.503	0	1.062	3	2.837	1
8.500	3	3.677	0	1.114	3	2.909	1
9.000	3	3.847	0	1.166	3	2.978	1
9.500	3	4.042	0	1.225	3	3.054	1
1.000	4	4.284	0	1.298	3	3.145	1
1.100	4	4.959	0	1.503	3	3.384	1
1.200	4	5.947	0	1.802	3	3.703	1
1.300	4	7.251	0	2.197	3	4.086	1
1.400	4	8.792	0	2.664	3	4.497	1
1.500	4	1.041	1	3.154	3	4.892	1

TABLE VI NORMAL SHOCK RELATIONS AT 200,000 FEET

T_s °K		P_s-P_O, psi		P_s/P_O		U/co	
1.585	4	1.165	1	3.530	3	5.177	1
1.776	4	1.386	1	4.200	3	5.655	1
1.995	4	1.524	1	4.618	3	5.942	1
2.239	4	1.629	1	4.938	3	6.160	1
2.512	4	1.799	1	5.452	3	6.484	1
2.818	4	2.190	1	6.636	3	7.150	1
3.162	4	2.856	1	8.655	3	8.154	1
3.548	4	3.577	1	1.083	4	9.123	1
3.981	4	4.164	1	1.261	4	9.854	1
4.467	4	4.798	1	1.453	4	1.058	2
5.012	4	5.885	1	1.782	4	1.172	2
5.623	4	7.310	1	2.214	4	1.305	2
6.310	4	8.737	1	2.646	4	1.428	2
7.080	4	1.044	2	3.164	4	1.562	2
7.943	4	1.277	2	3.869	4	1.727	2
8.913	4	1.528	2	4.631	4	1.890	2
1.000	5	1.816	2	5.501	4	2.061	2
1.122	5	2.132	2	6.459	4	2.235	2
1.259	5	2.397	2	7.262	4	2.374	2
1.412	5	2.619	2	7.935	4	2.488	2
1.585	5	2.812	2	8.519	4	2.585	2

TABLE VI NORMAL SHOCK RELATIONS AT 200,000 FEET

T_s °K		T_s/T_0		ρ_s/ρ_0		E_s cal/gm		γ_s
2.000	3	7.878	0	6.296	0	4.14	2	1.331
2.200	3	8.665	0	6.666	0	4.80	2	1.316
2.400	3	9.453	0	7.238	0	5.72	2	1.292
2.600	3	1.024	1	8.077	0	7.04	2	1.262
2.800	3	1.102	1	9.101	0	8.80	2	1.232
3.000	3	1.181	1	1.009	1	1.08	3	1.209
3.200	3	1.260	1	1.082	1	1.28	3	1.195
3.400	3	1.339	1	1.119	1	1.44	3	1.189
3.600	3	1.418	1	1.126	1	1.55	3	1.188
3.800	3	1.496	1	1.121	1	1.64	3	1.190
4.000	3	1.575	1	1.112	1	1.72	3	1.191
4.200	3	1.654	1	1.108	1	1.81	3	1.193
4.400	3	1.733	1	1.111	1	1.91	3	1.192
4.600	3	1.811	1	1.125	1	2.04	3	1.185
4.800	3	1.890	1	1.152	1	2.21	3	1.185
5.000	3	1.969	1	1.193	1	2.43	3	1.179
5.500	3	2.166	1	1.347	1	3.25	3	1.157
6.000	3	2.363	1	1.530	1	4.47	3	1.138
6.500	3	2.560	1	1.676	1	5.94	3	1.126
7.000	3	2.757	1	1.746	1	7.28	3	1.120
7.500	3	2.954	1	1.743	1	8.19	3	1.121
8.000	3	3.151	1	1.706	1	8.76	3	1.124
8.500	3	3.348	1	1.662	1	9.17	3	1.127
9.000	3	3.545	1	1.624	1	9.58	3	1.130
9.500	3	3.742	1	1.596	1	1.00	4	1.133
1.000	4	3.939	1	1.580	1	1.06	4	1.134
1.100	4	4.332	1	1.581	1	1.23	4	1.135
1.200	4	4.726	1	1.613	1	1.47	4	1.132
1.300	4	5.120	1	1.654	1	1.80	4	1.128
1.400	4	5.514	1	1.684	1	2.18	4	1.126
1.500	4	5.908	1	1.692	1	2.59	4	1.125

TABLE VI NORMAL SHOCK RELATIONS AT 200,000 FEET

T_s °K	T_s/T_o	ρ_s/ρ_o	E_s cal/gm	γ_s
1.585 4	6.242 1	1.680 1	2.89 4	1.126
1.778 4	7.004 1	1.612 1	3.43 4	1.132
1.995 4	7.859 1	1.511 1	3.76 4	1.141
2.239 4	8.818 1	1.412 1	4.00 4	1.152
2.512 4	9.894 1	1.352 1	4.40 4	1.159
2.818 4	1.110 2	1.366 1	5.38 4	1.157
3.162 4	1.245 2	1.418 1	7.04 4	1.151
3.548 4	1.397 2	1.423 1	8.80 4	1.150
3.981 4	1.568 2	1.383 1	1.02 5	1.155
4.467 4	1.759 2	1.350 1	1.17 5	1.159
5.012 4	1.974 2	1.364 1	1.44 5	1.157
5.623 4	2.215 2	1.378 1	1.79 5	1.156
6.310 4	2.485 2	1.363 1	2.14 5	1.158
7.080 4	2.788 2	1.354 1	2.56 5	1.159
7.943 4	3.128 2	1.358 1	3.13 5	1.158
8.913 4	3.510 2	1.344 1	3.74 5	1.160
1.000 5	3.939 2	1.327 1	4.44 5	1.162
1.122 5	4.419 2	1.299 1	5.20 5	1.166
1.259 5	4.958 2	1.245 1	5.82 5	1.174
1.413 5	5.564 2	1.181 1	6.33 5	1.185
1.585 5	6.242 2	1.113 1	6.75 5	1.197

TABLE VII NORMAL SHOCK RELATIONS AT 250,000 FEET

T_s °K		$P_s - P_o$, psi		p_s/p_o		U/c_o	
2.000	3	2.236	-2	6.722	1	7.467	0
2.200	3	2.727	-2	8.174	1	8.182	0
2.400	3	3.490	-2	1.043	2	9.164	0
2.600	3	4.593	-2	1.369	2	1.040	1
2.800	3	5.871	-2	1.748	2	1.169	1
3.000	3	6.986	-2	2.078	2	1.271	1
3.200	3	7.742	-2	2.302	2	1.337	1
3.400	3	8.244	-2	2.451	2	1.380	1
3.600	3	8.657	-2	2.573	2	1.415	1
3.800	3	9.085	-2	2.700	2	1.450	1
4.000	3	9.603	-2	2.853	2	1.491	1
4.200	3	1.028	-1	3.055	2	1.542	1
4.400	3	1.121	-1	3.330	2	1.608	1
4.600	3	1.248	-1	3.706	2	1.694	1
4.800	3	1.419	-1	4.212	2	1.802	1
5.000	3	1.639	-1	4.865	2	1.931	1
5.500	3	2.399	-1	7.113	2	2.323	1
6.000	3	3.307	-1	9.803	2	2.719	1
6.500	3	4.015	-1	1.190	3	2.994	1
7.000	3	4.402	-1	1.304	3	3.136	1
7.500	3	4.633	-1	1.372	3	3.220	1
8.000	3	4.844	-1	1.435	3	3.296	1
8.500	3	5.103	-1	1.512	3	3.385	1
9.000	3	5.450	-1	1.614	3	3.500	1
9.500	3	5.920	-1	1.753	3	3.647	1
1.000	4	6.538	-1	1.936	3	3.832	1
1.100	4	8.280	-1	2.452	3	4.307	1
1.200	4	1.064	0	3.152	3	4.878	1
1.300	4	1.329	0	3.938	3	5.450	1
1.400	4	1.570	0	4.651	3	5.924	1
1.500	4	1.748	0	5.179	3	6.255	1

TABLE VII NORMAL SHOCK RELATIONS AT 250,000 FEET

T_s °K	P_s-P_o, psi	P_s/P_o	U/c_o
1.585 4	1.842 0	5.455 3	6.425 1
1.778 4	1.977 0	5.855 3	6.672 1
1.995 4	2.086 0	6.178 3	6.870 1
1.239 4	2.304 0	6.824 3	7.232 1
2.512 4	2.883 0	8.538 3	8.082 1
2.818 4	3.841 0	1.137 4	9.314 1
3.162 4	4.775 0	1.414 4	1.038 2
3.548 4	5.419 0	1.604 4	1.107 2
3.981 4	6.218 0	1.842 4	1.187 2
4.467 4	7.790 0	2.306 4	1.328 2
5.012 4	9.724 0	2.879 4	1.483 2
5.623 4	1.[illegible]37 1	3.369 4	1.606 2
6.310 4	1.[illegible]73 1	4.067 4	1.764 2
7.080 4	1.694 1	5.018 4	1.959 2
7.943 4	2.017 1	5.975 4	2.139 2
8.913 4	2.411 1	7.141 4	2.339 2

TABLE VII NORMAL SHOCK RELATIONS AT 250,000 FEET

T_s °K	T_s/T_o	ρ_s/ρ_o	E_s cal/gm	γ_s
2.000 3	1.015 1	6.591 0	4.24 2	1.324
2.200 3	1.117 1	7.216 0	5.15 2	1.297
2.400 3	1.219 1	8.257 0	6.59 2	1.259
2.600 3	1.320 1	9.667 0	8.70 2	1.220
2.800 3	1.422 1	1.094 1	1.11 3	1.194
3.000 3	1.523 1	1.170 1	1.32 3	1.181
3.200 3	1.625 1	1.190 1	1.46 3	1.178
3.400 3	1.727 1	1.181 1	1.55 3	1.180
3.600 3	1.828 1	1.166 1	1.62 3	1.183
3.800 3	1.930 1	1.154 1	1.70 3	1.185
4.000 3	2.031 1	1.152 1	1.79 3	1.186
4.200 3	2.133 1	1.164 1	1.92 3	1.184
4.400 3	2.235 1	1.195 1	2.10 3	1.179
4.600 3	2.336 1	1.247 1	2.34 3	1.171
4.800 3	2.438 1	1.321 1	2.67 3	1.161
5.000 3	2.539 1	1.413 1	3.09 3	1.150
5.500 3	2.793 1	1.667 1	4.57 3	1.126
6.000 3	3.047 1	1.850 1	6.31 3	1.113
6.500 3	3.301 1	1.901 1	7.65 3	1.110
7.000 3	3.555 1	1.863 1	8.37 3	1.113
7.500 3	3.809 1	1.802 1	8.79 3	1.117
8.000 3	4.063 1	1.748 1	9.18 3	1.121
8.500 3	4.317 1	1.711 1	9.66 3	1.123
9.000 3	4.571 1	1.694 1	1.03 4	1.125
9.500 3	4.825 1	1.696 1	1.12 4	1.125
1.000 4	5.079 1	1.715 1	1.23 4	1.123
1.100 4	5.587 1	1.783 1	1.57 4	1.118
1.200 4	6.095 1	1.850 1	2.02 4	1.114
1.300 4	6.603 1	1.883 1	2.52 4	1.117
1.400 4	7.111 1	1.871 1	2.98 4	1.113
1.500 4	7.619 1	1.825 1	3.31 4	1.116

TABLE VII NORMAL SHOCK RELATIONS AT 250,000 FEET

T_s °K	T_s/T_0	ρ_s/ρ_0	E_s cal/gm	γ_s
1.585 4	8.050 1	1.772 1	3.48 4	1.119
1.778 4	9.033 1	1.646 1	3.71 4	1.129
1.995 4	1.013 2	1.529 1	3.90 4	1.140
2.239 4	1.137 2	1.466 1	4.30 4	1.146
2.512 4	1.275 2	1.503 1	5.40 4	1.142
2.818 4	1.431 2	1.571 1	7.22 4	1.135
3.162 4	1.606 2	1.571 1	8.96 4	1.135
3.548 4	1.802 2	1.508 1	1.01 5	1.142
3.981 4	2.022 2	1.471 1	1.16 5	1.145
4.467 4	2.269 2	1.503 1	1.45 5	1.142
5.012 4	2.545 2	1.519 1	1.82 5	1.140
5.623 4	2.856 2	1.488 1	2.12 5	1.144
6.310 4	3.205 2	1.488 1	2.56 5	1.144
7.080 4	3.596 2	1.499 1	3.17 5	1.142
7.943 4	4.034 2	1.480 1	3.77 5	1.144
8.913 4	4.527 2	1.465 1	4.50 5	1.146

TABLE VIII NORMAL SHOCK RELATIONS AT 300,000 FEET

T_s °K	P_s-P_o, psi	P_s/P_o	U/c_o
2.000 3	1.835 -3	7.244 1	7.729 0
2.200 3	2.512 -3	9.660 1	8.919 0
2.400 3	3.551 -3	1.392 2	1.047 1
2.600 3	4.624 -3	1.833 2	1.174 1
2.800 3	5.439 -3	2.127 2	1.285 1
3.000 3	5.844 -3	2.285 2	1.332 1
3.200 3	6.134 -3	2.397 2	1.366 1
3.400 3	6.424 -3	2.510 2	1.399 1
3.600 3	6.794 -3	2.650 2	1.438 1
3.800 3	7.297 -3	2.850 2	1.491 1
4.000 3	8.070 -3	3.151 2	1.565 1
4.200 3	9.225 -3	3.600 2	1.670 1
4.400 3	1.087 -2	4.242 2	1.807 1
4.600 3	1.308 -2	5.102 2	1.976 1
4.800 3	1.588 -2	6.192 2	2.170 1
5.000 3	1.914 -2	7.462 2	2.377 1
5.500 3	2.715 -2	1.057 3	2.823 1
6.000 3	3.158 -2	1.230 3	3.045 1
6.500 3	3.347 -2	1.303 3	3.138 1
7.000 3	3.493 -2	1.350 3	3.210 1
7.500 3	3.684 -2	1.435 3	3.299 1
8.000 3	3.976 -2	1.548 3	3.428 1
8.500 3	4.420 -2	1.721 3	3.614 1
9.000 3	5.058 -2	1.970 3	3.863 1
9.500 3	5.917 -2	2.304 3	4.174 1
1.000 4	6.992 -2	2.722 3	4.533 1
1.100 4	9.532 -2	3.711 3	5.287 1
1.200 4	1.183 -1	4.608 3	5.892 1
1.300 4	1.327 -1	5.168 3	6.245 1
1.400 4	1.402 -1	5.460 3	6.427 1
1.500 4	1.446 -1	5.630 3	6.535 1
1.585 4	1.466 -1	5.710 3	6.589 1
1.778 4	1.536 -1	5.980 3	6.759 1
1.995 4	1.737 -1	6.765 3	7.195 1
2.239 4	2.308 -1	8.985 3	8.278 1
2.512 4	3.107 -1	1.209 4	9.593 1
2.818 4	3.699 -1	1.440 4	1.047 2
3.162 4	4.068 -1	1.583 4	1.100 2

TABLE VIII NORMAL SHOCK RELATIONS AT 300,000 FEET

T_s °K		T_s/T_0		ρ_s/ρ_0		E_s cal/gm		γ_s
2.000	3	1.013	1	7.705	0	4.61	2	1.301
2.200	3	1.114	1	8.531	0	6.32	2	1.248
2.400	3	1.216	1	1.048	1	8.95	2	1.201
2.600	3	1.317	1	1.209	1	1.18	3	1.174
2.800	3	1.418	1	1.263	1	1.37	3	1.167
3.000	3	1.520	1	1.252	1	1.46	3	1.169
3.200	3	1.621	1	1.227	1	1.53	3	1.173
3.400	3	1.722	1	1.205	1	1.60	3	1.176
3.600	3	1.824	1	1.196	1	1.68	3	1.178
3.800	3	1.925	1	1.208	1	1.81	3	1.176
4.000	3	2.026	1	1.250	1	2.01	3	1.170
4.200	3	2.128	1	1.327	1	2.30	3	1.160
4.400	3	2.229	1	1.439	1	2.72	3	1.147
4.600	3	2.330	1	1.575	1	3.28	3	1.134
4.800	3	2.432	1	1.725	1	4.00	3	1.122
5.000	3	2.533	1	1.869	1	4.85	3	1.112
5.500	3	2.786	1	2.082	1	6.90	3	1.100
6.000	3	3.040	1	2.074	1	8.00	3	1.101
6.500	3	3.293	1	1.989	1	8.45	3	1.105
7.000	3	3.546	1	1.909	1	8.79	3	1.110
7.500	3	3.800	1	1.855	1	9.26	3	1.113
8.000	3	4.053	1	1.835	1	9.98	3	1.115
8.500	3	4.306	1	1.852	1	1.11	4	1.113
9.000	3	4.560	1	1.899	1	1.27	4	1.110
9.500	3	4.813	1	1.966	1	1.49	4	1.106
1.000	4	5.066	1	2.035	1	1.77	4	1.102
1.100	4	5.573	1	2.129	1	2.42	4	1.098
1.200	4	6.080	1	2.128	1	2.99	4	1.098
1.300	4	6.586	1	2.058	1	3.34	4	1.102
1.400	4	7.093	1	1.964	1	3.52	4	1.107
1.500	4	7.600	1	1.870	1	3.62	4	1.113
1.585	4	8.030	1	1.796	1	3.66	4	1.118
1.778	4	9.010	1	1.664	1	3.82	4	1.123
1.995	4	1.010	2	1.616	1	4.31	4	1.132
2.239	4	1.134	2	1.707	1	5.75	4	1.124
2.512	4	1.272	2	1.784	1	7.77	4	1.118
2.818	4	1.428	2	1.744	1	9.22	4	1.121
3.162	4	1.602	2	1.653	1	1.01	5	1.129

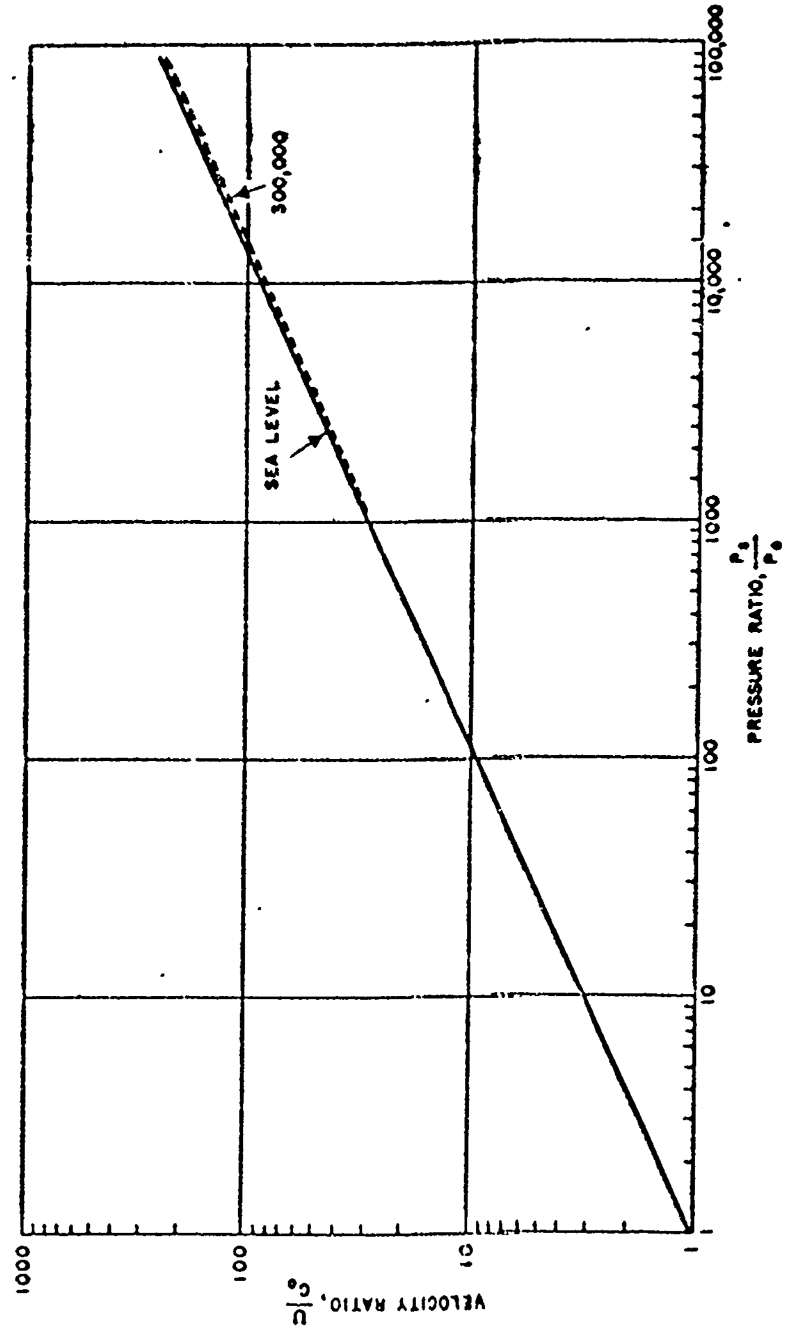

FIG. I SHOCK VELOCITY RATIO VS SHOCK PRESSURE RATIO AT VARIOUS ALTITUDES

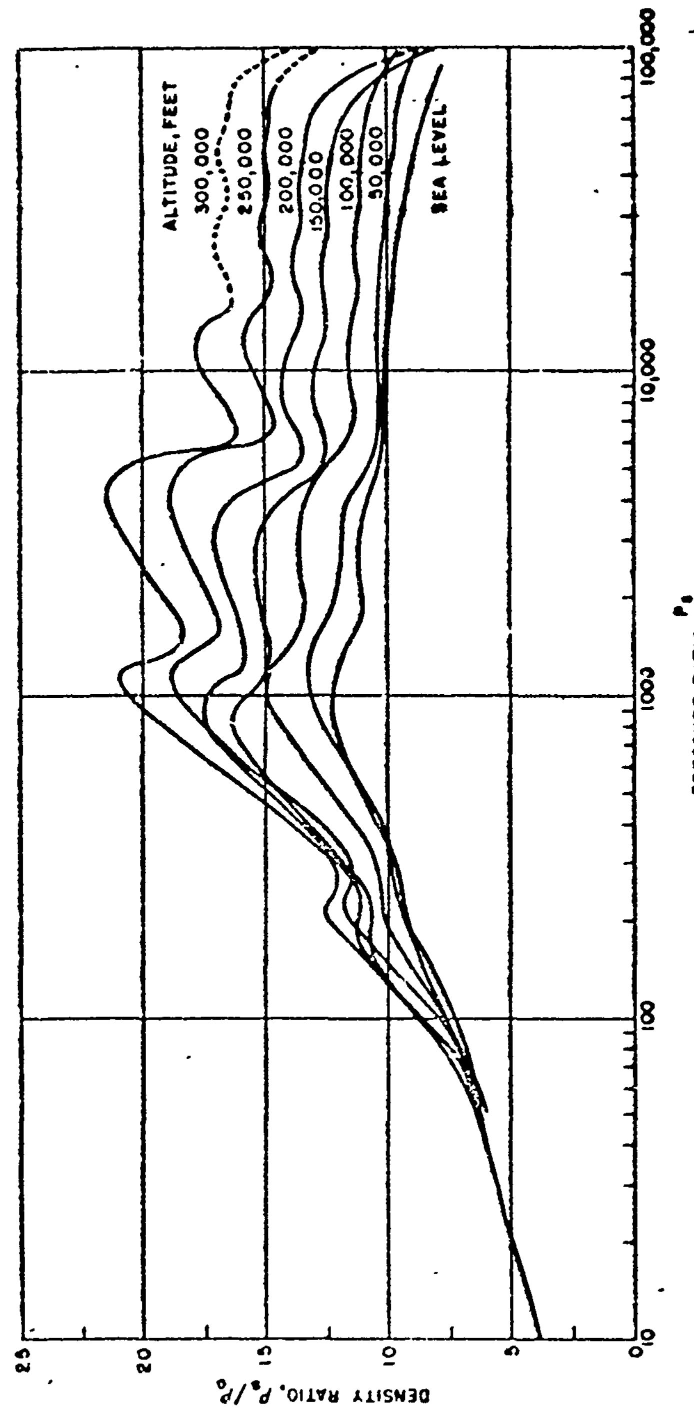

FIG. 2 SHOCK DENSITY RATIO VS SHOCK PRESSURE RATIO AT VARIOUS ALTITUDES

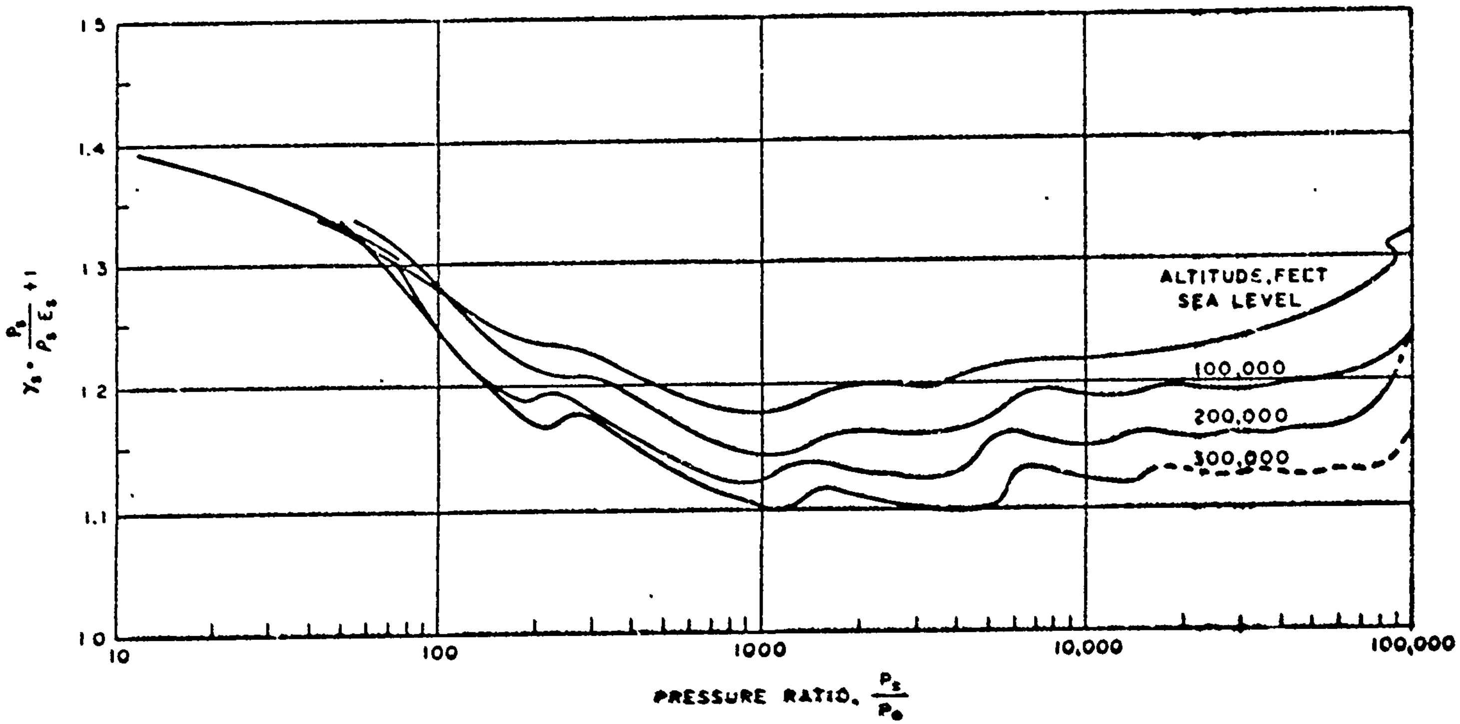

FIG.3 EFFECTIVE SPECIFIC HEAT RATIO BEHIND THE SHOCK VS SHOCK PRESSURE RATIO AT VARIOUS ALTITUDES

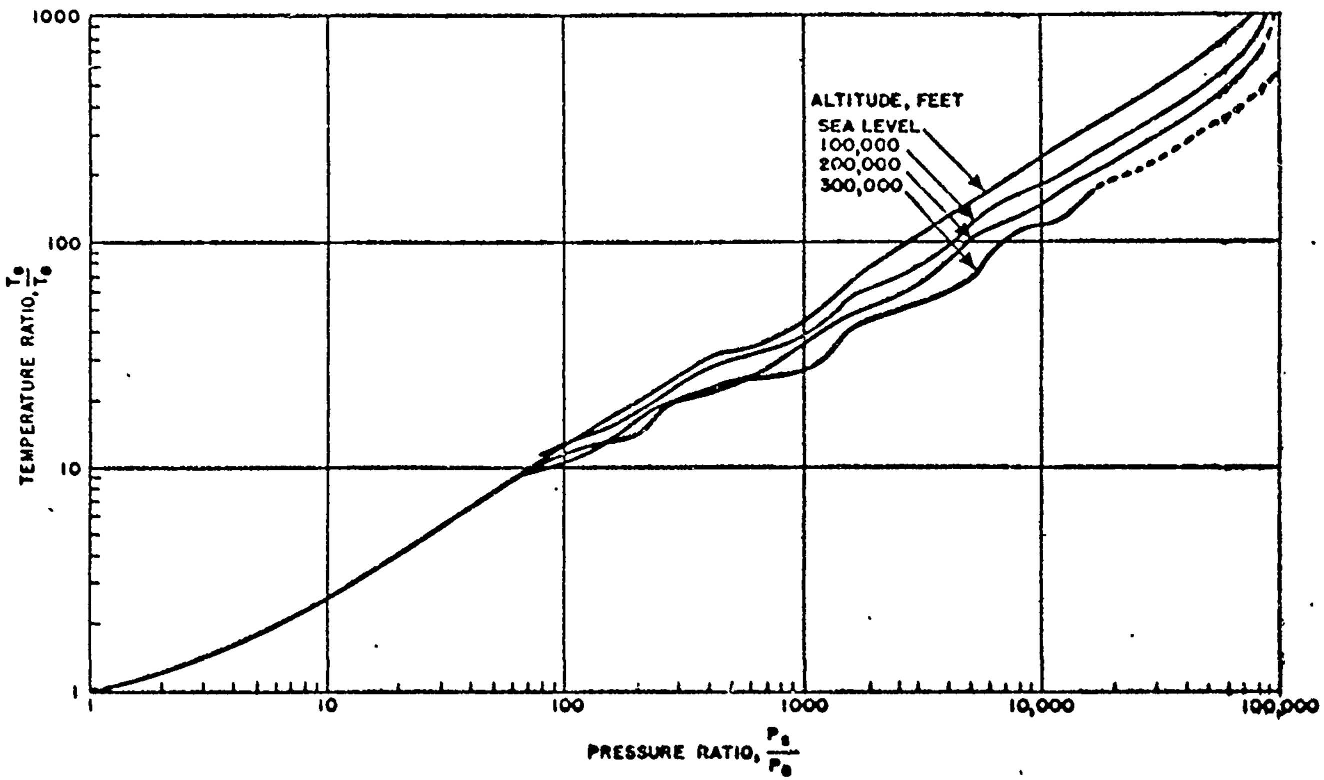

FIG. 4 SHOCK TEMPERATURE RATIO VS SHOCK PRESSURE RATIO AT VARIOUS ALTITUDES

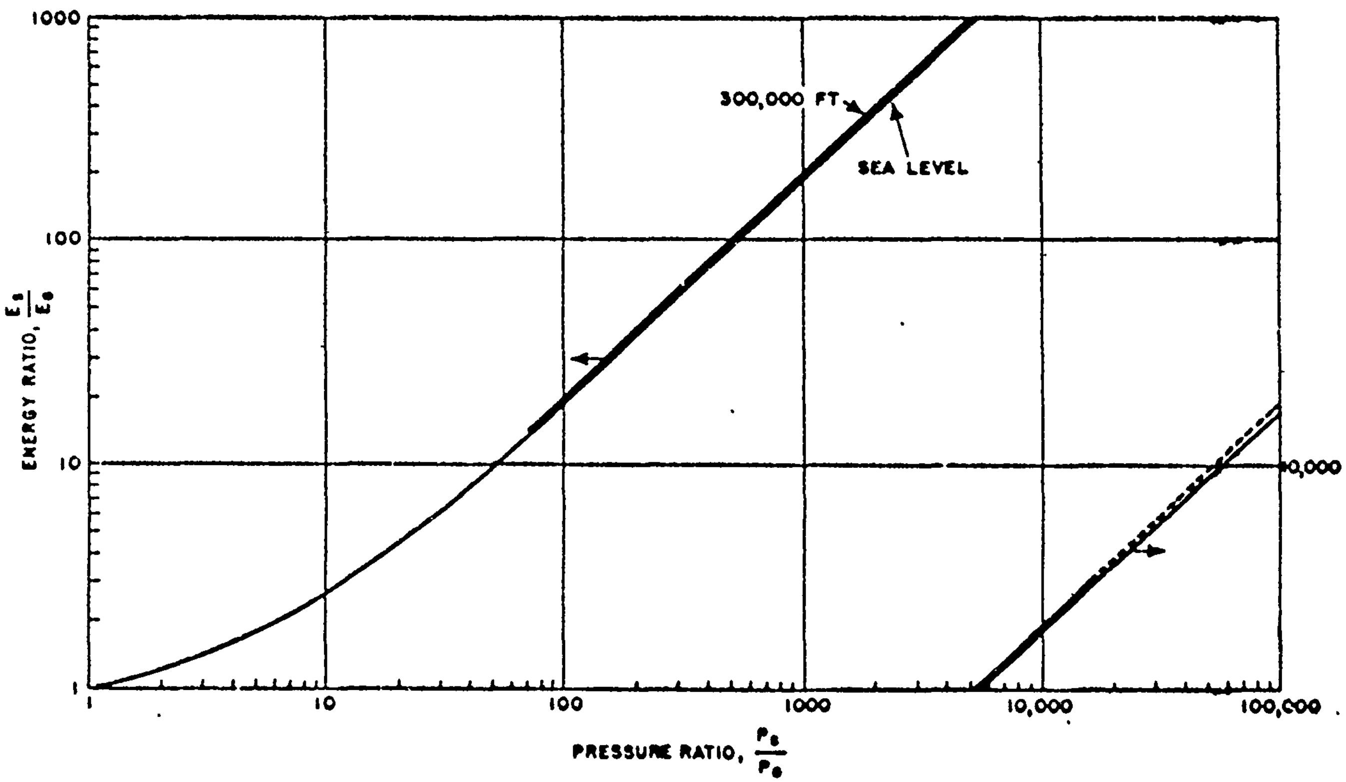

FIG. 5 SHOCK SPECIFIC INTERNAL ENERGY RATIO VS SHOCK PRESSURE RATIO AT VARIOUS ALTITUDES